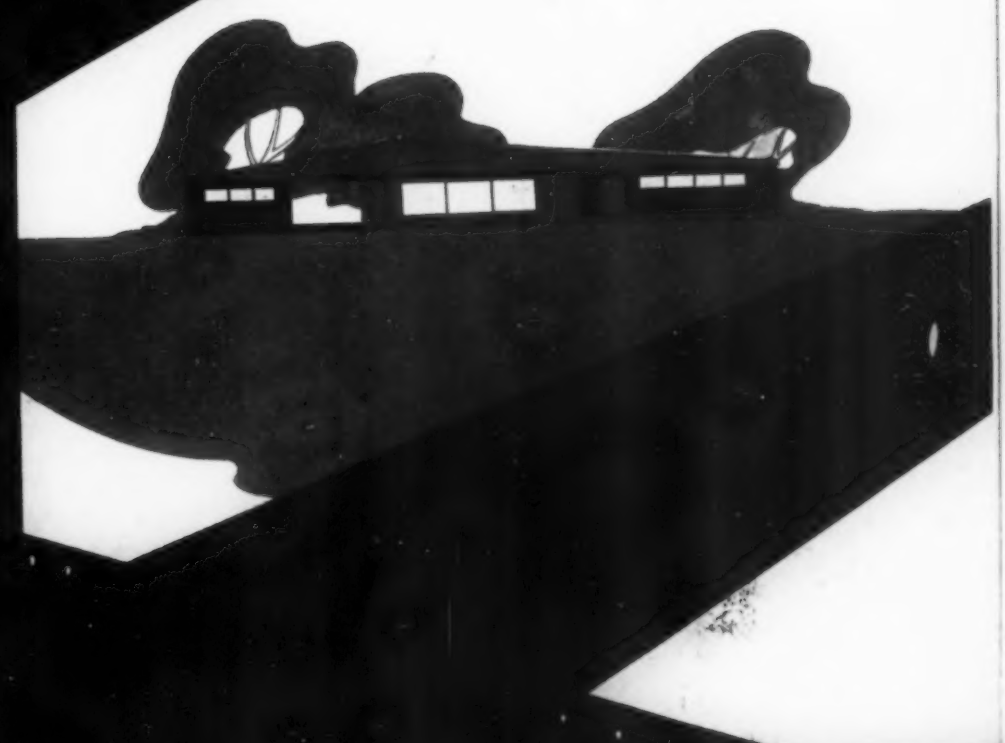
METAL PROGRESS

AUGUST 1947



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SURFACE COMBUSTION CORPORATION • TOLEDO 1, OHIO

Metal Progress

August 1947

Vol. 52, No. 2

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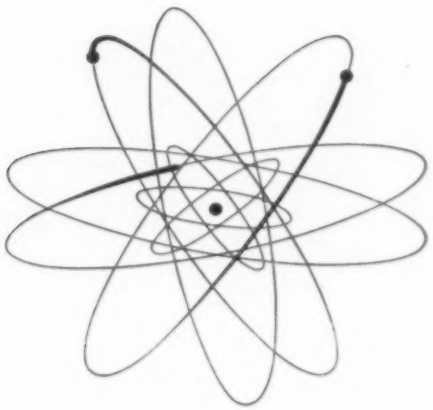
RYERSON STEEL

A Carburizing Experiment With Radioactive Carbon

By J. K. Stanley
Research Engineer, Magnetic Dept.
Westinghouse Research Laboratories
East Pittsburgh, Pa.



One of the isotopes of carbon — the one with atomic weight 14 — is radioactive and can now be had from the Atomic Energy Commission in combined form as barium carbonate. Making a carburizer of this with activated charcoal enables a test to be made of current theories about the mechanism of carburization and the action of so-called energizers.

THE RECENT availability of radioactive carbon C^{14} has aroused interest in diffusion and the possibility of auto-radiographic experiments with such radioactive carbon in iron. This radioactive carbon is available only combined in the form of barium carbonate and may present some difficulty to the research worker who wishes to introduce the carbon of this compound into iron. Fortunately a method is available for doing this, and it is the object of this paper to describe it.

In the pack carburizing method of treating steel, the carburizing medium is a mixture of activated charcoal (other charcoals are not suitable) and a substance called an energizer or catalyst which can be the carbonate of barium, strontium, sodium or potassium. Activated charcoal by itself is a poor carburizer, but in the presence of the energizer, considerable carbon is supplied to the iron for effective carburization.

This communication is concerned with a report on how radioactive carbon was introduced into iron from the radioactive compound $BaCO_3$, hereafter designated as $BaC'O_3$ because of its content of the carbon isotope C^{14}.

Preliminary Experiments — Some preliminary experiments were first run to see how effective ordinary $BaCO_3$, whose carbon has atomic weight of 12, would be as a carburizing mixture. Three hollow cylinders were made from iron of high purity, as shown in Fig. 1. The walls of the cavity were electroplated with a layer of copper 0.003 in. thick, so carburization would be localized — that is, on only the top and bottom of the cavity.

For carburizing, one capsule was filled with pulverized 40-mesh activated charcoal; the second capsule was filled with a mixture of 90% activated charcoal and 10% ordinary $BaCO_3$; the third was set aside for eventual use with $BaC'O_3$. Each half of two capsules was filled with the carburizer; then over one of the halves a layer of tissue paper was stuck to the lip of the cup with sodium silicate (water glass); then the upper fitting was screwed into the lower one. The threads were coated with "aquadag" with the expectation that the capsule could be opened after carburizing, but this hope was not realized.

The two capsules were heated together in a dry hydrogen atmosphere for 50 hr. at 1740° F. (950° C.). After carburizing, the hollow cylinders were cut through the threads. Cylinders 1 in. in diameter and 1 in. long were machined from the end of each carburized capsule in such a manner

that one of the ends of each cylinder corresponded to the bottoms of the cavity. Layers were then taken from the cylinder ends and duplicate analyses were made for carbon. Carbon penetration curves for the activated charcoal and for the 90% charcoal + 10% $BaCO_3$ mixture are shown in Fig. 2. The upper curve shows the effectiveness of $BaCO_3$ in aiding carburization. The role of $BaCO_3$ in carburization will be discussed in a following section. Suffice it here to say that some metallurgists have held that this carbonate is a major source of CO_2 which reacts with the incandescent charcoal to form CO, which is the real carrier of carbon to the steel's surface. Others hold that the principal activity of the energizer arises from BaO — or volatile Na or K, if sodium or potassium carbonate is the energizer — which acts as a catalyzer because of its affinity for the CO_2 generated at the surface of the steel. It would seem that if the carbon from the $BaCO_3$ could be "tagged" its eventual resting place could be determined, and evidence supporting one or the other of these theories would be forthcoming.

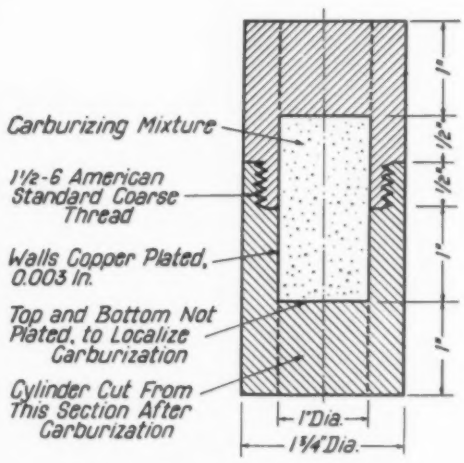


Fig. 1 — Iron Capsule Used for Carburizing Experiments

Introduction of Radioactive Carbon Into Iron — Having demonstrated the effectiveness of ordinary $BaCO_3$ in carburization with C^{12}, the next step was to use this technique in introducing C^{14} into iron, using $BaC'O_3$ obtained from the Manhattan Engineer District, Oak Ridge, Tenn. At the present time it is available in one millicurie* amounts; this represents roughly 125 mg. of $BaC'O_3$ with an isotopic activity of roughly 13%.

In order to make a carburizing mixture out of the material, this small amount of $BaC'O_3$ was diluted by mixing with ordinary $BaCO_3$ to 1 g. To this mixture, 9 g. of pulverized activated charcoal was added and the mixture was well mixed. To have some idea of how much C^{14} would be introduced into the iron by this method, the relative activity of the $C+BaC'O_3$ mixture was measured both before and after carburizing. The mixture was put into a beaker and exposed to a specially designed β-ray Geiger tube with a very thin (3.44 mg. per sq.cm.) mica window and a conventional scaling circuit. A sheet of aluminum 0.04 in. thick had to be placed between the sample and the Geiger tube to reduce the number of counts.

After checking the activity in counts per minute, the carburizing mixture was introduced into the third pure iron capsule and was carburized like the others: 50 hr. at 1740° F. The capsule was then carefully cut apart in order to save all carburizing compound and prevent contamination of work bench and personnel. The remaining carburizing mixture was then checked on the Geiger tube under conditions as identical as possible with those used in the initial counting. Results obtained on the Geiger counter are:

Before carburization: 162 counts per min.

After carburization: 19 counts per min.

These results indicate that about 85% of the original radioactivity had disappeared — presumably had diffused into the iron. The radioactivity of the iron after light grinding and polishing was rather high, but the counts from the iron and the carburizing mixture cannot be compared because of differences in self-adsorption; in iron the β-rays come only from the surface of the sample.

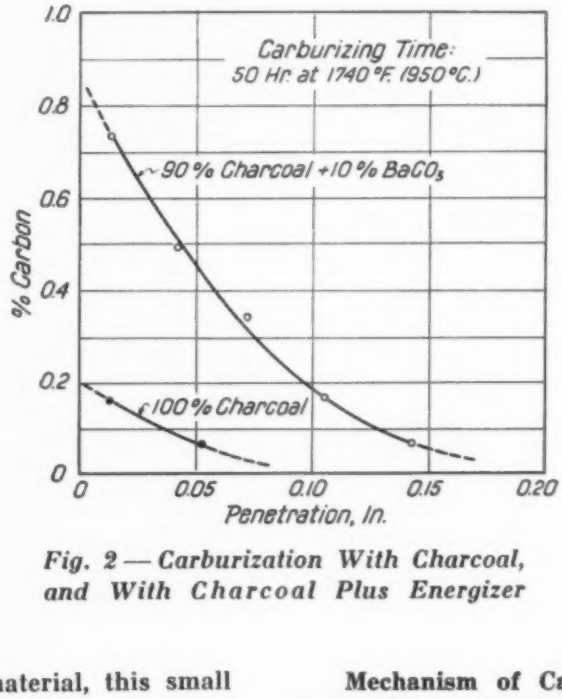


Fig. 2 — Carburization With Charcoal, and With Charcoal Plus Energizer

Mechanism of Carburization — This experiment with radioactive carbon offers an explanation for the function of energizers in carburizing compounds. The mechanism has already been

*A "curie" is defined as 3.7×10^{10} disintegrations per sec. occurring in the radioactive element; a "millicurie" is therefore 3.7×10^{7} disintegrations per sec.

proposed in "The Action of Carbonate Catalysts in the Carburization of Steel" by T. C. Fong and R. A. Ragatz, published in ⊖ *Transactions*, V. 32, 1944, p. 162, and is supported by this study.

In the absence of energizers or catalysts the transfer of carbon from the activated charcoal to the iron is accomplished by the diffusion of CO from the carbon-gas interface to the gas-metal interface, the transfer of carbon from the gas to the metal, the diffusion of the resulting CO_2 gas in the opposite direction, and its regeneration as CO by the charcoal. The reaction occurring at the carbon-gas interface at the carburizing temperature is:

$$CO_2 + C \rightleftarrows 2CO$$

To start the reaction some CO_2 originates from the adsorbed gas on the charcoal and also from its reaction with entrapped air. The reaction at the gas-metal interface which results in the deposition of carbon on the iron is:

$$2CO + \text{iron} \rightleftarrows CO_2 + C_{(\text{in iron})}$$

The present writer has discussed this carburization reaction in a series of three papers in *Iron Age* for Jan. 21, Jan. 28 and Feb. 4, 1943.

The rate of carburization of steel with activated charcoal alone is slow because of the limited amount of CO available in the gas atmosphere. The addition of an energizer or catalyst increases the amount of available CO in the following manner:

As the system is being heated to the carburizing temperature and while it is at temperature, the energizer is reacting with the charcoal. For $BaC'O_3$ the reaction would be:

$$BaC'O_3 + C \rightarrow BaO + 2C'O$$

The C'O concentration at the carbon-gas interface, as well as the gas-metal interface, is higher for this reaction than when no catalyst is present. The C'O then reacts in the presence of iron:

$$2C'O + \text{iron} \rightleftarrows C'O_2 + C'_{(\text{in iron})}$$

The $C'O_2$ formed in the carburizing reaction then reacts with the BaO as follows:

$$BaO + C'O_2 \rightleftarrows BaC'O_3$$

This $BaC'O_3$, with its concentration of C^{14} reduced by that part which has gone into the iron, is then free to react further with carbon, and the cycle repeats itself until the greater part of the radioactive carbon is removed from the cycle by absorption in the iron.

The other explanation of the catalytic effect of the so-called energizers is that they are merely sources of CO_2. It is also implied that the catalyst undergoes decomposition in a progressive manner and eventually reaches a state of exhaustion. However, Fong and Ragatz found no evidence that carbonate catalysts decompose in a progressive and continuous fashion — in fact they found that most of the CO_2 is evolved from decomposition of the carbonate catalyst during the heating cycle, and gas evolution ceases shortly after the carburizing temperature is reached. They also found that $CaCO_3$ and $MgCO_3$, which yield CO_2 very readily, are valueless in carburizing compounds. Likewise that if barium (or sodium, or potassium) is present in the carburizer as carbonate, hydroxide, acetate or nitrate in stoichiometric amounts, the rate of carburization is the same. Finally, they exploded the "exhaustion" theory by heating mixed compound for several hours until all the CO_2 had been evolved from the energizer, then introducing a piece of steel preheated to the same temperature; carburization started and progressed at a rate normal for the conditions of the experiment.

Homogenization of C^{14} in Iron — During the carburization of iron by the carburizing medium, a concentrational gradient of carbon of the type shown in Fig. 2 is set up. Such carburized iron may not be suitable for experiments in which it is necessary to have the carbon distributed uniformly. Two methods are available for homogenization. One obvious method is to anneal in an inert atmosphere or vacuum for a long time, for example, several days at 2200° F. (1200° C.) or higher. One is never certain, however, that such material *has* become homogeneous unless analyses are made. A better method appears to be the remelting of the carburized material in a small high frequency vacuum furnace. This method is satisfactory provided the iron used has been sufficiently deoxidized to prevent reaction of any carbon that may be present, ordinary and radioactive, with dissolved oxygen. ⊖

Critical Points

By the Editor

SAW, for the first time, an assembly of aluminum parts made by furnace brazing — an operation common for steel and copper alloys for lo these many years. Furthermore, the assembly isn't a minor item at all, but a torque converter for White Motor Co. busses; it rides between engine and gear box and transmits over 200 hp. W. B. Terbeck, assistant works manager for White, explained that the unit is 16 in. diameter, consists of three pieces rotating on a common axis, the first being a centrifugal pump driven by the gas engine, the second a hydraulic turbine driven by the pump and keyed to the drive shaft, and the third reaction member nested between the two. Oil is the fluid medium. The torque converter not only simplifies the rest of the transmission, but avoids much gear shifting. Better than that, it is like a gas-electric drive — it boosts the engine torque by 375% at low starting speeds, and thus saves jerks that annoy the passengers and rack the mechanism. . . . . Both "pump" and "turbine" consist of dished inner and outer shells, and between them 18 accurately curved blades of air-foil section. Originally the pump, turbine and reactor were sand castings, but their cost was high due to rejects for core shifts and porosity on X-ray inspection; also a lot of machining, filing, buffing and balancing was necessary. Furthermore, their efficiency was impaired from the rough surfaces of the inner passages through which the oil swept. Lastly, their strength was too close to danger from explosion from centrifugal force if the engine raced. The stress analysis laboratory of Aluminum Co. of America in Cleveland then tackled the problem of building up each piece from individual units — a 16-in. dished forging of 61-S for outer shell, a pressed annular ring for the inner shell (this is made of $\frac{3}{16}$-in. 61-S sheet with 5% its thickness of brazing alloy on one side), and blades of alloy 612, cast in permanent mold and coined for accurate contours but especially for square corners where blades rest against inner and outer shell — an essential for penetration and building up a good fillet of brazing alloy.

Torque converter for bus engines

All oil-swept surfaces are thus beautifully smooth; porosity problems have vanished; furthermore, variations in power requirements for various engines are met merely by changing the shape and size of the blades. . . . . Robert Bultman, liaison engineer for White Motor Co., says that four things are absolutely necessary for successful brazing: First, proper assembly — blades are located by dowel pins in blind holes drilled to templet; clearances are accurate to limits of forging, pressing and coining dies. Second, cleanliness — before assembly each piece is dipped in hot 5% caustic and cold 50% nitric acid. Third, fluxing — a creamy paste is brushed evenly over contacting surfaces. Fourth, temperature control — held to 1100° F. ± 5° in Electric Furnace Co. roller hearth furnaces originally used for nitriding. . . . . After the parts are assembled and stirrups of ⅛-in. brazing wire closely fitted to joints next the outer shell forging, pumps are placed flat on their side in closely fitting cup-like carriers, and weighted down with an old steel gear. Everything then goes by time cycle; 30 min. to braze (1100° F.); cool 1.5 min. in fixture outside furnace to 950° F. until the joint metal freezes; pour out molten flux; quench in water at 130° F.; age at 310° F. for 6 hr. Rejects on inspection are cleaned, fluxed, new brazing wire placed alongside defective joints and the furnace cycle repeated. . . . . As for results, the bursting speed has been increased over twice that of the casting, the over-all cost reduced more than half (½), and the efficiency as a power transmitting unit increased. Score another one against the diehards who can't see that it is sometimes cheaper to handle 20 simple parts than a single complicated one. Also remind them of the gray-beard who could never change from rubble masonry to massive concrete because he could see no economy in crushing solid rock into small sizes merely to cement it together again.

Brazing an aluminum unit to transmit 200 hp.

SINCE the Editor once wrestled with a definition for the word "steel", he enjoyed hugely Karl Darrow's discourse before the A.I.M.E.'s Iron and

Steel Division on "metal" as the ancients, the alchemists, the chemists, the lexicographists and now the physicists have defined it. (Darrow, Bell Telephone Laboratories' physicist, runs neck-and-neck with General Electric's Saul Dushman as the Editor's favorite writer on physical science.) . . . . The definition: "A metal is a substance which may or may not have the kind of luster characteristic of metals (like galena); which may or may not be malleable (like putty); which is ductile (like gum); which is opaque (like stone); which melts (like ice); which contains free electrons (like hydrogen); which hangs on to its phlogiston; and is accepted as a metal by the A.I.M.E."

What is metal?

A PROMINENT area has been set aside at the International Amphitheater in Chicago for the ASM's Second Metallographic Exhibit, held concurrently with the 30th National Metal Congress and Exposition. The rules will be found in the advertisement on page 290 of this issue; they are few and simple. No entry fee is charged. Rewards are ribbons in each classification, and a certificate and a substantial cash prize for the best micro in the show.

Metallographic Exhibit

IMPRESSED more and more by the thought that laboratory and production men are handling pretty tricky things these days, and disaster lurks behind any carelessness. An outstanding example is ammonium nitrate, long used by the chemical, fertilizer and explosive industries. (Amatol is a half-and-half mixture with TNT.) Commercially pure ammonium nitrate was classed as "inert", so inert that caked stockpiles were blasted, until three explosions shortly after World War I put it in the "dangerous" if not "explosive" class. The worst of these destroyed Oppau, Germany, a city as large as Texas City, the scene of the very recent disaster. Chemical engineers are still puzzled by the fact that so stable a thing may suddenly let go; the best guess is that the explosions were due to carbonaceous impurities. Like its chemical relative, potassium nitrate, it is apparently inert until mixed with carbon, when it becomes gunpowder! Perhaps the paper bags containing the ammonium nitrate at Texas City, plus heat of an outside fire, were enough to trigger the explosion.

Explosions, mysterious or preventable

Another item of sad news comes from Ottawa, where an ASM member was killed by an explosion of improperly dried alloying compounds dropped into a magnesium melt. This, according to the coroner's investigation, was an instance where familiarity breeds contempt. Face shields, asbestos gloves and leg protectors, and those other items of standard safety equipment in a foundry *must* not be disregarded by a squad leader who dashes out from an office to supervise the alloying or pouring of a melt.

Still other news comes in about perchloric acid — now a very common reagent in metallurgical and chemical laboratories. W. R. White, head of Hughes Tool Co.'s laboratory in Houston, Texas, recalls that he was once fuming perchloric acid in a flask held around the neck by a rubber-covered clamp. Droplets of concentrated acid condensed around the mouth of the flask and dribbled down outside. As soon as they met the rubber clamp they exploded like a Chinese firecracker. J. T. Baker Chemical Co. has recently formulated a list of no less than eight incidents (underwriter's word for trouble), and German chemical literature since 1936 has described four explosions, one of which wrecked the entire laboratory. Then also there is the explosion of the electroplating tank in Los Angeles that killed 16.

Perchloric acid — a bad actor

From other sources come warnings that shattering explosions may happen when the condensate is merely scraped off the inside of a slate hood. William C. Bowden, technical director of Ledoux & Co., New York City, lists these precautions about hoods and ducts:

Perchloric acid fumes should never be allowed to come in contact with wood. (If wood has soaked up perchloric acid there is no method known of rendering it safe.)

Perchloric reactions should be carried on in separate welded steel hoods with joints ground smooth, vented directly to the outside, without connections to other ducts. (One explosion came from acid lodged in joints of an Alberene stone hood.) Long service without incidents has been experienced with down-draft hoods whose walls and exhaust ducts are continually sprayed with water.

Baffle plates should be prohibited, unless they can easily be removed and washed.

Inner surfaces of hoods *and ducts* should be hosed down generously at regular intervals, paying particular attention to recesses.

The American Society for Testing Materials' committee on chemical analysis has appointed a group to formulate safe practices for handling perchloric acid. Any reader of "Critical Points" who has other relevant information would do well to communicate with Mr. Bowden. ASM

Influence of Water Vapor and Methane

on the heat treatment of steel

in a $CO:H_2$ Gas Atmosphere

By Henry M. Heyn
Manager, Heat Treat Division
Surface Combustion Corp.
Toledo, Ohio

At the Western Metal Congress, early this year, Mr. Heyn gave a technical address "Controlled Atmospheres and Their Practical Application" which described the principal types of equipment for producing the atmospheres, and their uses in the heat treatment of metal. The portion of this address which is reproduced below gives a very brief summary of the entire subject, but elaborates on those portions which described the utility of a cracked gas-air mixture containing about 20% CO, 40% H_2, 40% N_2 and controlled amounts of water vapor and methane.

THE USE of gas atmospheres in heat treating is not new. The first known application of an atmosphere in the processing of metal was practiced by early blacksmiths. These early workers in metals were familiar with the fact that iron and steel would oxidize while hot, forming "mill scale", as it is known today. By proper manipulation in the open fire forge, in which coal or charcoal was the fuel, they found they could largely prevent the formation of scale. The art practiced by the blacksmith has long since passed from the scene of modern American industrial operations. Some of his processes are still in use, since they are fundamental, but methods of application now are such as to be barely recognizable.

When furnaces replaced forges for the treatment of steel, the products of combustion were found to cause undesirable changes in surface characteristics of the metal and could not be controlled without affecting the proper combustion of the fuel. In other instances, leakage of air into the furnace through seams or door openings made it difficult and sometimes impossible to control the nature of the atmospheres existing around the load. Thus, not only the kind of atmosphere but its control became important in preventing oxidation and other changes not only at the metal surface but for some distance below it.

Not much was known about the proper constituents of the gases in the furnace until long after the blacksmith's crudely controlled practices had ceased to be used. Surface scaling, decarburization, and sometimes an increased carbon content during furnacing, were condoned as necessary evils. After heating, the undesirable parts of the surface were removed.

It soon became evident that it was necessary to develop an efficient heating method which did not allow the products of combustion to contact the work. The development of the radiant tube heated furnace and the electric furnace was a long step toward making this possible. When the furnace is heated by these means and is so designed that air infiltration cannot occur, various gases can be admitted and maintained around the material under precise control.

Thus the way was cleared for the most important single development which has occurred in the field of heat treating during the past decade — prepared gas atmospheres, and their practical application. By surrounding the metal, which is undergoing various heating and cooling operations, with either a single gas or a mixture of several gases, certain chemical reactions with the metals may be induced or prevented. The machines required to produce these atmospheres and the practical application of these gases to the various processes have been and can be classified under the term, "The Science of Gas Chemistry for Heat Treating".

To appreciate more thoroughly the practical application of atmospheres as applied to clean and bright annealing, to gas carburizing, skin recovery, dry cyaniding, clean hardening, and atmosphere forging, a knowledge of the gas preparation units that are employed to make the gases for these processes is necessary.

Although there are some 33 classes of atmospheres (see the data sheet, page 256-B), the generators used for the preparation of controlled atmospheres can be classified into two broad groups — those of the exothermic type and those of the endothermic type. The exothermic type makes an atmosphere from a fuel that burns with a partial percentage of the air required for complete combustion. However, sufficient air is mixed with the gas to *support* combustion and, therefore, the reaction proceeds without outside help. This type of generator, diagrammatically sketched in Fig. 1, is capable of making a lean combusted gas and through a range to what is regarded as a rich combusted gas. A lean combusted gas will have a CO content of 1.5%; the CO_2 percentage would then be approximately 10.5%. As the atmosphere becomes richer, the CO increases and the CO_2 decreases to where the rich combusted gas would contain about 10.5% of CO and only 5% of CO_2.

The endothermic type, which requires heat from external sources to reform the air and fuel gas mixture, has a wider application. Of the endothermic design there are two types most generally in use — one using charcoal and the other using a natural gas or a petroleum gas such as butane or propane. The charcoal type, which makes an atmosphere of approximately 34% CO and less than 2% hydrogen (the balance being nitrogen), has a restricted application, although it is a splendid gas for carburizing or heat treating the high carbon steels. It is restricted in its application to some of the other treatments because of its dryness and difficulties in increasing and regulating its dew point.

For that reason the reacted gas or reformed fuel gas and air which results in an atmosphere of 20% CO, 40% hydrogen, controlled water vapor, trace of methane, the balance being nitrogen, has a wider and more practical application. (A self-contained unit to produce this gas, the so-called "RX Generator", is shown in Fig. 2.) This gas has certain advantages which make it particularly good for the heat treatment of medium and high

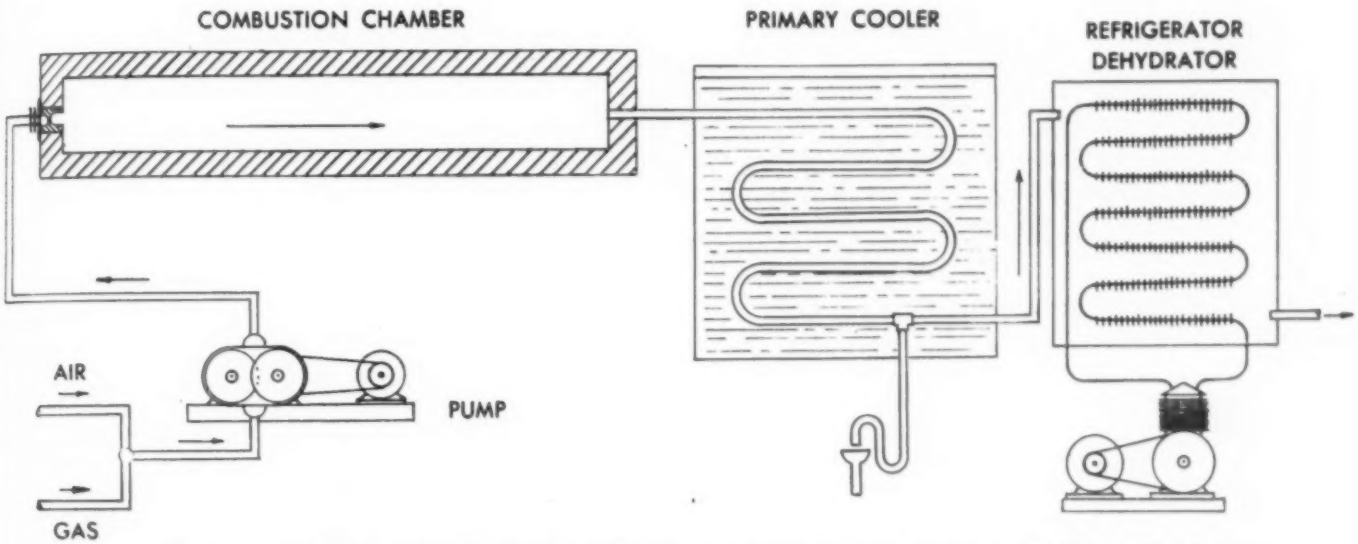


Fig. 1 — Diagram of Exothermic Type of Atmosphere Generator, Widely Used for Bright and Clean Annealing of Low-Carbon Steels and Nonferrous Metals and Alloys*

*EDITOR'S NOTE — Controlled atmospheres for nonferrous metals will be broadly discussed in a later article by William Lehrer.

carbon steels, for carburizing, skin recovery (that is, carbon restoration) and for dry cyaniding.*

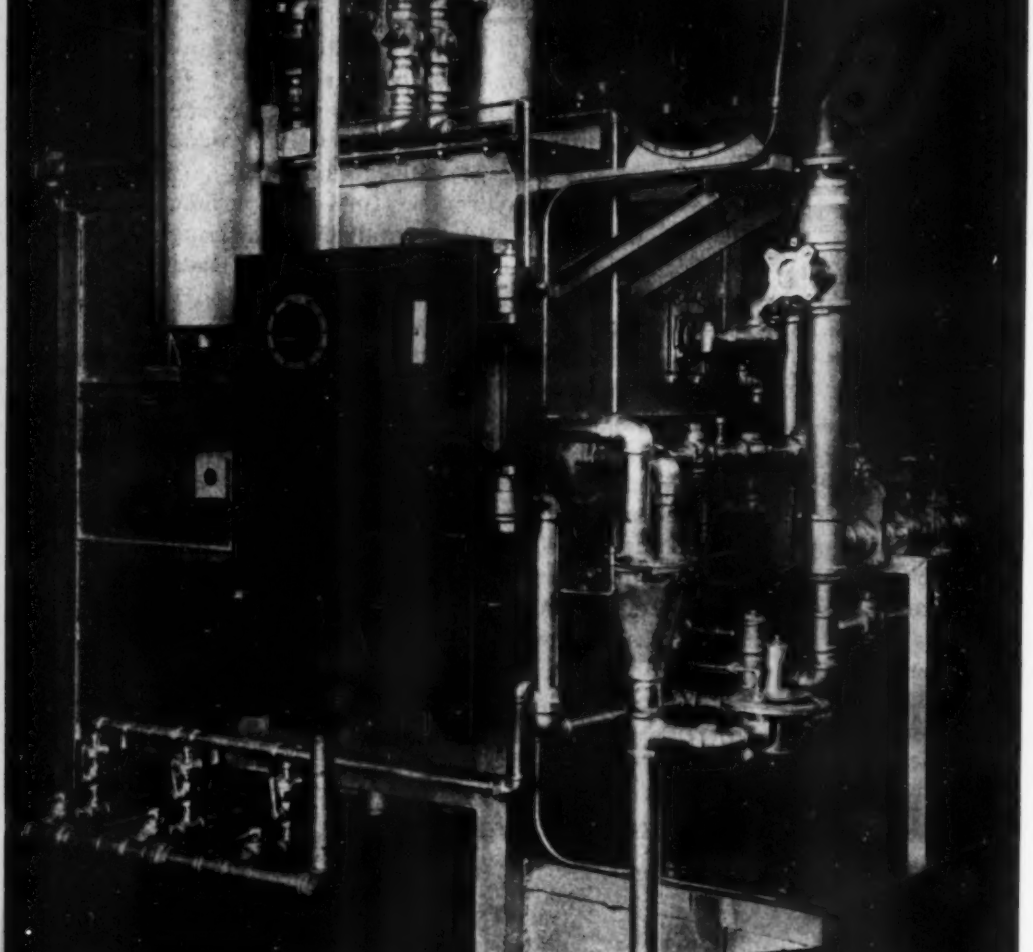
Before discussing the action of the 20% CO, 40% H_2 gas as a working whole, it may be well to describe the reactions of the individual gases on steel surfaces at heat treating temperature.

Oxygen reacts with ferrite to form iron oxide and with carbon of the cementite at an even more rapid rate, thus lowering the carbon content of its surface. Oxygen therefore is decarburizing. The free gas must be eliminated from protective atmospheres, as well as the oxygen-containing compounds CO_2 and H_2O in such proportions that they easily give up oxygen to the hot steel surface.

Nitrogen is entirely passive to ferrite and a nitrogen atmosphere is entirely satisfactory for bright heat treating of low-carbon steels. If completely pure and bone dry, it will also be passive to high-carbon steel; the presence of even traces of moisture will, however, cause decarburization.

*EDITOR'S NOTE — Dry cyaniding is done in a carburizing atmosphere to which ammonia has been added. The process and equipment will be discussed in a forthcoming article by Walter H. Holcroft.

Fig. 2 — Generator for Making 20% CO + 40% H_2 Gas by Cracking Mixture of Methane and Air in a Catalytic Chamber at High Temperature. (Surface Combustion Corp.)



Carbon dioxide, CO_2, is reactive with ferrite; part of it gives up half its oxygen and causes oxidation. Similarly, it is also decarburizing. Since the product of either reaction is the formation of carbon monoxide, CO, its effect upon steel surfaces may be offset or counterbalanced by mixing it with certain proportions of the latter gas. For low-carbon steels, the ratio of CO to CO_2 may be in the order of about two to one. For high-carbon steels, depending upon the temperature of treatment, this ratio may be as high as 100 to 1. The physical chemist would note these facts by writing:

$$3CO_2 + 2Fe \rightleftarrows Fe_2O_3 + 3CO$$

and

$$CO_2 + Fe_3C \rightleftarrows Fe_3 + 2CO$$

the double arrows meaning that the reaction moves in one way or the other until an equilibrium ratio of CO_2 to CO exists in the gas in contact with the hot steel surface. This specific ratio, however, depends very greatly upon the temperature, and to a minor extent upon the partial pressure — which in actual practice is related to the amount of inert nitrogen that is present.

It follows from the second equation above that when it moves from right to left, carbon monoxide is reactive with ferrite (at high temperatures) to form iron carbide. It is therefore carburizing, and is most desirable for the heat treatment of high-carbon steel. At low temperatures it tends to decompose, with the formation of carbon dioxide and free carbon which deposits on the steel as soot.

Hydrogen is highly reducing to iron oxide and is, therefore, a powerful deoxidizer. If bone dry, hydrogen has no decarburizing effect on high-carbon steel except at elevated temperatures, where it has a slight reaction with carbon to form methane.

Water vapor is oxidizing to ferrite and combines with carbon in steel to form carbon monoxide and hydrogen. It is reactive to a steel surface at moderate temperatures, and is the principal cause of blueing during the cooling cycle. It will shortly be explained that water vapor can be used as the key to action of the 20-40 gas.

Hydrocarbons, more specifically methane, CH_4, are

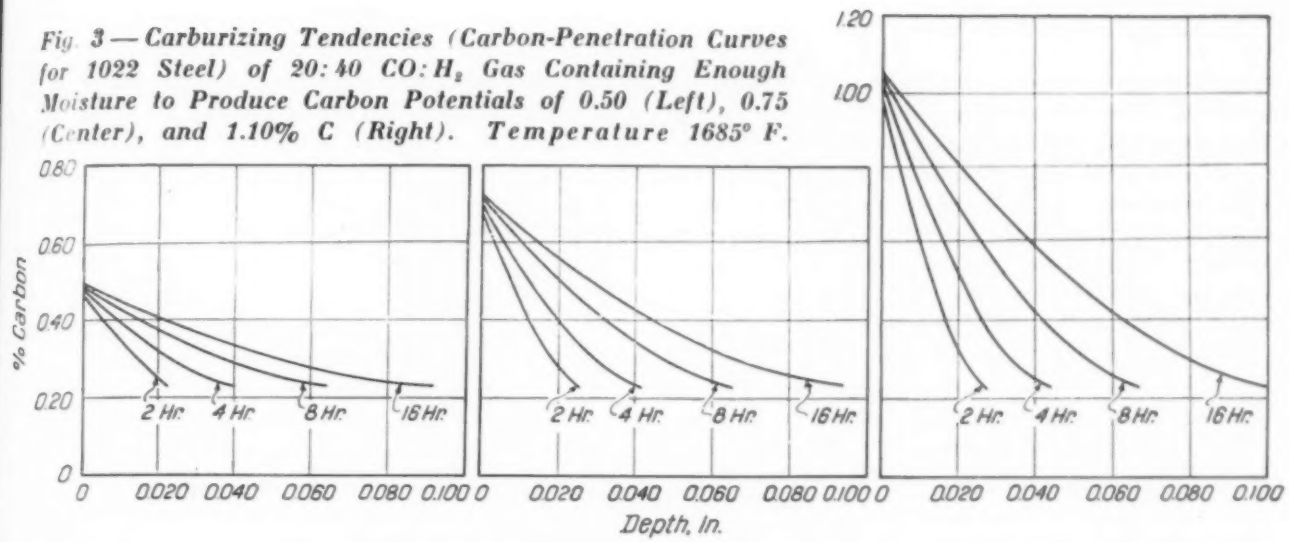


Fig. 3 — Carburizing Tendencies (Carbon-Penetration Curves for 1022 Steel) of 20:40 CO:H_2 Gas Containing Enough Moisture to Produce Carbon Potentials of 0.50 (Left), 0.75 (Center), and 1.10% C (Right). Temperature 1685° F.

carburizing gases. They are subject to thermal decomposition at annealing and hardening temperatures, liberating hydrogen and depositing soot on the steel. This sooting tendency is particularly noticeable when more than 10% CH_4 is added to the base gas.

Until the past year it has been common to think of the individual action of each species of gas. Obviously, with some of the gases tending to decarburize and some to carburize, the situation seemed very complicated. However, a recent paper* has taken long-known fundamentals and, through a new interpretation, shown that when a constant base gas such as the 20% CO, 40% H_2 mixture is used, its carburizing potential can normally be determined by either the dew point or the CO_2 content. Since dew point can be measured much more accurately than CO_2 percentages, it is logical to choose dew point as the single control factor.

To establish the concept of dew point control, over 100 tests were run in the Surface Combustion Corp.'s research laboratory in which the water vapor content or dew point of the 20-40 gas was varied to obtain atmospheres which would be neutral to steels of different carbon contents at the various temperatures at which heat treating is normally performed. The results closely approximated the theoretically computed quantities.

With this fundamental work established, it was possible to form some practical conclusions for the wide application of reacted gas atmospheres, using as a base the 20% CO, 40% H_2 atmosphere. The gas, as produced in commercial equipment such as shown in Fig. 2, may be used directly to obtain any desired carbon concentration in the austenite range. The dew point is very simple to control in practice. One merely adjusts the air-gas ratio at the entrance of the generator, usually by turning a dial. For example, a 0.60% carbon steel may be heated without scale or change in carbon by adjusting the gas to a 24° dew point. In addition to this use of the 20-40 gas, it can be made potently carburizing by adding small amounts of methane or propane. Thus the generator gas is ideal for carburizing, carbon restoration, hardening, and dry cyaniding.

In order to make practical use of the concept of dew point control of carbon concentration, the operator must understand the role of *time at temperature* as it affects these processes. When a low-carbon bar is carburized, carbon is put into the surface of the metal from where it diffuses toward the core at a rate depending upon the temperature and the surface concentration. It is not difficult to understand that the surface concentration will be determined by the difference between the rate at which carbon is added by the gas and the rate at which it diffuses inwardly. Consequently, the surface carbon may be controlled at any desired level by making the gas as potently carburizing as necessary.

To obtain surface carbons of 1% or less, generator gas as produced can be employed with the dew point set as desired. For surface carbons above 1% the generator gas cannot be made sufficiently potent by simple dew point adjustment. Methane, CH_4, may then be added to give the desired result. When this is done, the dew point in the furnace will be lower than can normally be obtained with the generator gas alone and, therefore, the dew point may still be used as the "carburizing potential indicator", so-called.

When carburizing is carried out in this way, the carbon at the steel's surface will approach more and more closely, as time passes, the carbon potential of the atmosphere. When the surface carbon reaches the atmosphere potential, no further change will occur at the surface, but the

*"Carbon Concentration Control" by E. G. deCoriolis, O. E. Cullen and Jack Huebler, ⊜ *Transactions*, V. 38 (1947), p. 659.

case depth will continue to increase by diffusion inward at the normal rate.

Contrasted to the above example, it may be desired to carburize completely through a thin sheet, to restore surface carbon to an original level, or to heat without change in carbon. In such instances there is no important flow of carbon by diffusion from the surface, and, therefore, the carbon concentration at the surface will very quickly become the carbon potential of the gas and will remain exactly that as long as the heating is prolonged. Thus the operator should keep these different operations quite separate in his thinking.

To demonstrate all of the foregoing principles, a series of tests were completed, and some of the results are shown in Fig. 3. In these tests very thin strips of low-carbon steel and test bars of 1022 steel were treated at 1685° F. for various time intervals in atmospheres of various carbon potential. In the first test the generator was so adjusted as to give a dew point in the furnace of 30° F. and thereby give the atmosphere a carbon potential of 0.50%. The thin strip very quickly was carburized to exactly 0.50% carbon, having reached that value in 1 hr. Prolonged heating for as much as 14 hr. did not change the value from 0.50% carbon. This justifies the statements made above. The test bars which were run at the same time showed analyses as given in the left graph of Fig. 3. Here it will be observed that the surface carbon is gradually approaching 0.50% carbon as a limit. As the concentration-depth gradient becomes less steep, and thus conducts less carbon from the surface, the surface carbon approaches more nearly the atmosphere potential.

The other two diagrams of Fig. 3 record additional tests of this same type, conducted for carbon potentials of 0.75 and 1.10%, with similar results. In these tests the dew points were held at 20° F. and 8° F. respectively.

Having completed these tests, experiments were conducted to show the effect of the more commonly used methane, CH_4, and the base gas atmosphere. The generator was adjusted so that a dew point of 8° would be obtained in the furnace, and then enough CH_4 was added to give 1.6% CH_4 in the furnace and a +3° F. dew point. Tests identical to the above were then run, and the results shown in Fig. 4. The carbon in the *thin strip* increased regularly and apparently without limit, having attained the value of 1.80% in 24 hr. (We take the 2-hr. reading as indicative of the relative carburizing potential of the gas.) The +3° F. dew point may also be indicative of a moderately high potential in the particular furnace used. On the other hand, the *test bars*, whose carbon analyses are plotted in the left-hand diagram, showed moderately high skin carbon.

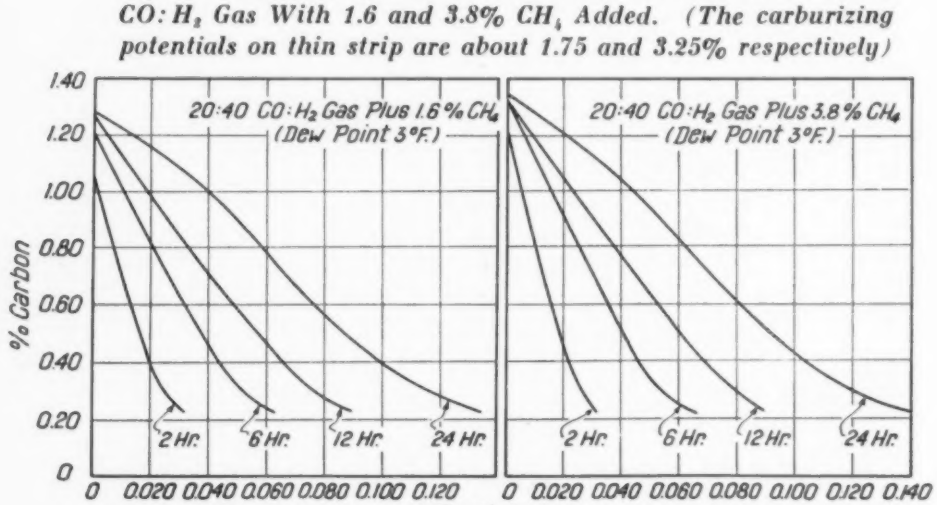
In another test enough CH_4 was added to give 3.8% CH_4 and a −3° F. dew point in the furnace. In this instance the strips obtained extremely high carbon values at the end of the test, reaching 3.30% carbon. Again the 2-hr. value of 1.60% C and the low dew point of −3° F. are indicative of a very high carburizing potential. In these runs the test bars reflect the same results, having high enough skin carbons to give free cementite.

Thus it was demonstrated that the 20-40 gas, properly regulated and without addition, can give the exact carbon value desired and that the dew point is the single control needed. With addition of CH_4 the gas may be used for common carburizing, and its action controlled — at least approximately — by the dew point.

One other point of interest may be obtained from these tests. In the central diagram of Fig. 3, case depths to 0.40% carbon are plotted as a function of time and carburizing potential. Case depth increases as the square root of the time, as would be theoretically expected; obviously the case depth also increases quite appreciably with higher surface carbons.

All the foregoing would have greater interest if it had practical application. A while ago we were told that a continuous gas carburizing furnace was producing material that had a soft skin. This

Fig. 4 — Carburizing Tendencies on Test Bars Heated in 20:40 CO:H_2 Gas With 1.6 and 3.8% CH_4 Added. (The carburizing potentials on thin strip are about 1.75 and 3.25% respectively)



furnace was 6 ft. wide and 40 ft. long. It was divided into four zones, two heating zones and two carburizing. Field tests of the atmospheres in these zones showed that the first part of this furnace — that is, the preliminary heating zone — had a carbon potential of 1.18%. The second part of the heating zone was approximately the same. In the first section of the soaking zone the carbon potential was 1.58%. However, in the last part of the soaking zone the carbon potential was 0.98%. It is obvious that while a fine job of gas carburizing was being done in the middle zones of this furnace, the work was being decarburized in the last zone. After the carbon potential was corrected the decarburized material disappeared.

It has been shown that dew point has a very important place in atmosphere. The more research into atmospheres and the effects of the atmospheres at various dew points, the greater became the need for a machine that would automatically record the dew point at intervals of 3 to 10 min. The recorder so developed is shown in Fig. 5. It operates on the simple principle of a refrigerated mirror principle. A sample of the gas is caused to flow over a mirror which in turn is refrigerated on the rear side by a stream of evaporating gas. At some point, as the temperature of the mirror drops, condensation or fog starts forming on the mirror. The temperature of the mirror is then just a little below the temperature where the gas being tested is saturated with water vapor — that is, just a little below its dew point. This fog eventually breaks a light beam, which sets into action a half-dozen electronic tubes, and a dot is made on a chart. This dot is the dew point of the gas — no more, no less. (Likewise a pointer is moved to indicate the temperature.)

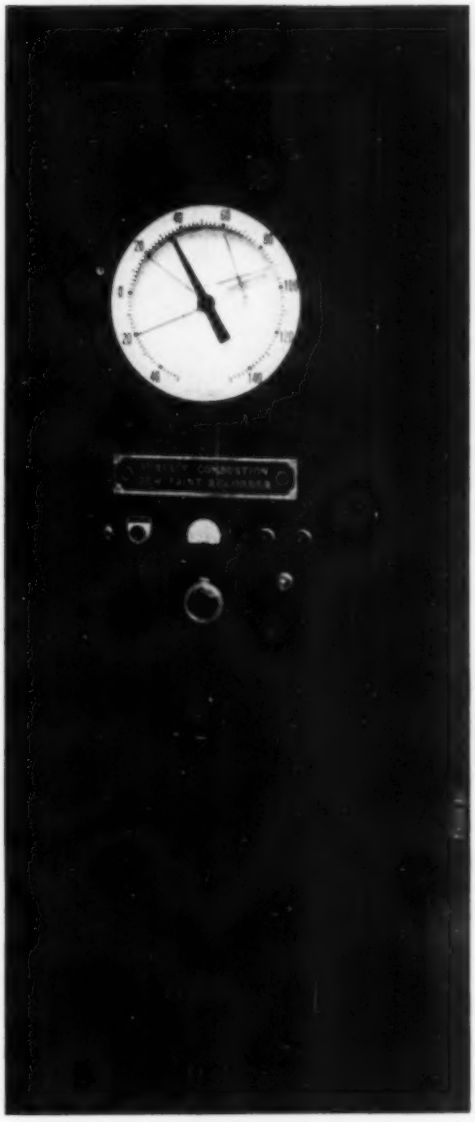


Fig. 5 — Automatic Dew Point Indicator and Recorder

It is an invaluable machine where atmosphere furnaces are being used. It tells the operator or the control man whether the atmosphere is right and whether the furnace is performing correctly. Dew point control is not complex. There are some allowable variations in practical operation. For example, if a furnace atmosphere is supposed to have a reacted gas dew point of 10° F., if the record indicates that it has gone to 40° F. it would immediately warn the operator that something is wrong. On the other hand, if the dew point fluctuates between 10 and 15° F., the operator can with assurance know that the heat treated product is going to be uniformly good.

To answer the frequently put question, "What progress has been made in gas carburizing during the last 20 years?", not so long ago it was not possible to carburize material in a gas atmosphere without forming a lot of soot. As high as 33% CH_4 was necessary (based on the gas flow then in use) and this caused about 5 lb. of carbon to be deposited each hour. At the present time, continuous and batch-type carburizing furnaces are running with approximately 3.4% CH_4, which throws out about 1 lb. of carbon each hour, and this applies only to carburizing furnaces where a high surface carbon concentration is desired. (It does not apply to clean hardening or carbon restoration because for these applications an addition of CH_4 gas is not required.) Eventually it should be able to drop the CH_4 content to approximately 0.9% and the amount of free carbon being liberated in a furnace would then be only 0.1 lb. — one-tenth what it is at the present time and one-fiftieth the amount of a decade ago.

The present achievement should not be discouraging because the work coming out today is clean. There is no visible carbon on the material. One pound of carbon distributed over a good many hundred square feet of surface area is infinitesimal.

Pressure Welding of Stainless Steel

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This article is a chapter for the section on welding in the forthcoming third edition of "The Book of Stainless Steels". Pressure welding or solid phase welding is the fundamental process involved in the art of powder metallurgy; in this article, however, the meaning is restricted to the welding of bars, tubes or other commercial shapes into mechanical parts by heating the abutted joint by external gas flames and pressing the parts together as soon as the metal reaches the temperature of plastic action.

SOLID PHASE welding or pressure welding is the process of joining metals by the application of heat and pressure without utilizing a liquid phase. The heat presumably provides desirable atomic mobility for diffusion and recrystallization and the pressure acts to produce the necessary intimate contact between the surfaces and to break up thin oxide films that cover them.*

In practice, pressure welding has been used to join stainless steel members where the shape, dimensions, or mechanical property requirements of the assembly have been such that other fabricating methods are not adequate, the quantities required are not sufficient to warrant more expensive dies, or the nature of the metal is such that more conventional forging methods may cause too many rejects from edge cracks or may involve too large a percentage of trim scrap. (See Fig. 1.)

The mating surfaces to be welded are ground smooth and approximately parallel. They are carefully degreased, placed in contact, and a pressure of about 10,000 psi. is applied, usually by means of hydraulic pumps and appropriate fixtures or dies. The weld zone is heated, frequently by means of one or more oscillating oxy-acetylene torches with multiple flames, so that the mating surfaces or interface and a moderate volume of metal alongside reach a temperature approximating that recommended for optimum forging of the particular type of stainless being welded.† As the steel becomes plastic it begins to upset at and near the interface, and this is permitted to continue until the desired shortening (and upset) is obtained. Heating is then discontinued, the weld is allowed to cool, the bead of upset metal is removed by machining, and the weld is ready for inspection.

Welding Procedure—The welding process is not difficult in principle, but careful attention to detail is essential to produce good welds. Likewise, it is far easier to get first-quality joints in low-carbon steel than it is in the high-alloy stainless types. Sections to be welded should be simple geometric shapes. Rounds, squares, rectangles, or simplified variations of these are the most practical to weld. Irregular shapes greatly complicate the heating and holding or jigging problems. The mating surface must be ground to a flat, smooth finish. The necessary fineness of the finish is dependent on several variables, but probably should not exceed 50 micro-inches. The flatness should be such that a feeler gage of 0.001-in. thickness cannot be slid into the joint when the pieces are held together with little or no pressure. (An exception

*A. B. Kinzel, Adams Lecture, "Solid Phase Welding", *Welding Journal*, December 1944, V. 23, p. 1124. A. R. Lytle, "Oxyacetylene Pressure Welding", *Welding Journal*, December 1944, V. 23, p. 1145.

†"Evaluating the Forgeability of Steels", pamphlet by Timken Roller Bearing Co., Steel and Tube Division, Canton, Ohio.

to this occurs when the surfaces are purposely ground at a slight angle to compensate for differential expansion caused by the temperature gradient. In large cross sections, particularly, the joint tends to open up around the edges and become oxidized there before the center has reached the plastic stage, unless the heating rate is reduced and differential heating adopted. The latter is recommended, rather than an angular opening at the joint, since any oxide forming in such an opening is difficult to eliminate.*) The ground surfaces should be carefully degreased before welding and the clean surfaces placed together in the fixture. Carbon tetrachloride is suitable for cleaning. Pressure is applied as nearly normal to the mating surfaces as possible and the heating heads are lighted.

The heating heads are designed to oscillate about ⅜ in. either side of the parting line so that a hot band, about ¾ in. wide, is produced. Uniform heating is important. Particularly troublesome is the unequal expansion of large sections by nonuniform heating. This forces some areas to open up during the heating cycle. Undue oxidation consequently occurs at the surfaces to be welded and unless a sufficiently large upset takes place, the oxide remains at the interface in such amounts that it cannot diffuse, and this line of inclusions results in an inferior weld. See Fig. 2. With reasonably good practice the oxide particles are almost completely absorbed into the base metal when low-carbon steels are welded. However, oxides are thought to be a major cause of substandard joints in heat treated alloy steels, and are minimized by careful fitting of joints, control of heat, pressure and amount of "gather" or upset.† Diffusion of complex chromium-iron oxide and carbide particles in the stainless steels is even more difficult by any after-treatment, and so it is doubly important to prevent their appearance in the first place.

Proper positioning of the heads and adjustment of the flame will minimize the temperature gradient that exists between the outside and the inside of the metal. Too rapid heating, with its coincident large heat gradient, will burn the outside layers of the piece before the inside core reaches the proper temperature. Experimental work, using several thermocouples embedded in the samples under test, indicates that 2200° F. is about the temperature that must be attained across the interface if satisfactory welds are to be obtained without excessive upsets. However, there is need for experimental work to correlate weld temperature with amount of upset needed to produce a good weld for the various stainless steels. At any rate, temperature is the variable with most influence on final quality; faulty bonding is the result of too low a temperature; if too high, the joint metal will show grain boundary oxidation (burning). At the present time, cut-and-try methods are used to develop an acceptable program, which is then usually followed by time clock.

Temperature Variations Across Joint

As the metal temperature rises, plastic deformation (creep) begins, counteracted only in

Fig. 1—Edge View of Pressure Welded Joint in Type 321 Stainless Steel Ring, Ground and Etched for Inspection. 11 in. i.d., 12½ in. o.d., 5½ in. long as welded

*C. J. Burch *et al.*, "Pressure Welding Stainless Steel Rings", *Steel*, Jan. 13, '47, p. 88.

†See a series of articles by Leslie Fine *et al.* in *Metal Progress*, V. 49, p. 108, 350 and 530.

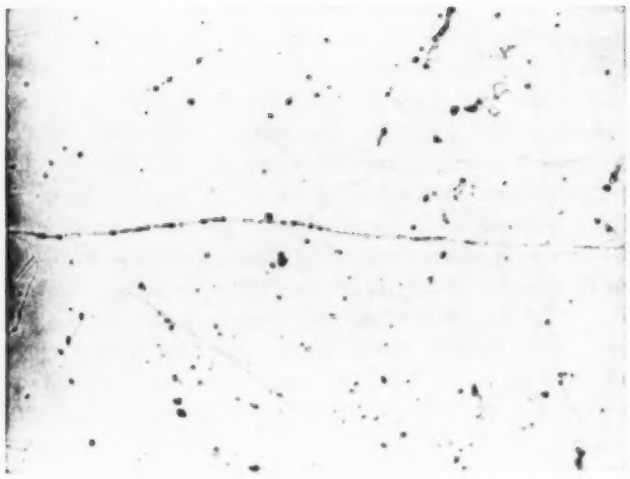

Fig. 2 — String of Oxide Particles in Film at an Inferior Pressure Weld in Type 321, Remaining After Solution Treatment (Water Quench After 1 Hr. at 1900° F.)

part by expansion due to temperature effects, and this continues until the hot short-time strength of the steel balances the applied load. Initial pressure should be high enough to get noticeable movement by the time the temperature reaches 1350° F., thus tending to close minute openings at the joint. If the system is a closed hydraulic one, the pressure then drops rather rapidly as temperature increases. Figure 3 gives data on this point, taken from two experimental welds, ¾ x 2½ in. in cross section, wherein 10,000 psi. was placed on the mating surfaces by a small hydraulic press. Heating was done by heads containing 33 No. 74 orifices; oxygen and acetylene gas were injected at the rate of 100 cu.ft. per hr. When the 50-psi. oxygen flame had been on for 0.9 min. the surface temperature had reached 2080° F. and the center 1750°, and pressure started to drop (through upset). One minute after starting, the surface and center temperatures were 2150 and 1860° F. respectively and the pressure had dropped to 8000 lb. — and so on down to a pressure of 2000 psi. 1.5 min. after start of heating.

When the proper welding temperature is reached, as determined by trial, additional pressure is rapidly applied until the desired shortening is obtained. At the same time the heating flames are turned off to prevent excessive burning of the bead metal as the upset pushes the metal closer to the burner orifices. Pressure is maintained for a few seconds (primarily to hold the welded unit in alignment) then released as the joint cools.

The weld bead is then usually machined off and the weld is ready for inspection.

Heating Equipment

The necessary heating equipment for oxy-acetylene gas mixtures usually consists of water-cooled heating heads with numerous small orifices, as shown in Fig. 4, and the necessary manifolds, and pressure recording and regulating equipment. Precise control of gas and oxygen flow is important; lack of generally available equipment for this purpose makes exact duplication of results difficult. However, where heating times are greater than 1.5 min., moderate variations in gas flow,

Table I — Tensile Properties of Welds

Joint	Ultimate Strength	Yield Strength	Elongation	Reduction of Area	Fracture
Type 347					
Welded at 2100° F.	77,000	46,500	28.0	29.1	Flat at weld
Welded at 2200° F.	77,000	44,000	39.0	61.0	Cup cone
Welded at 2200° F. and forged	88,000	51,000	55.0	68.5	Cup cone
Unwelded control	88,500	48,500	57.0	59.2	Cup cone
Type 321					
Through weld	78,000	45,000	40.5	44.8	
Original bar	83,000	46,000	61.5	75.1	
Type 310					
Through weld	75,000	40,000	46.0	51.9	
Original bar	75,000	42,000	51.0	50.2	

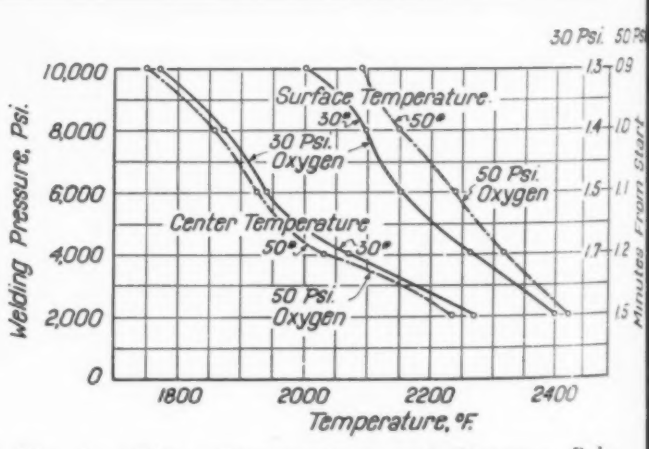

Fig. 3 — Time, Temperature and Pressure Relationships at Surface and Center in Two Welds (Made With Burner Oxygen at 50 Psi. and 30 Psi. Respectively) in Type 310, 2½ x ¾-In. Section. It is apparent that a considerable difference in surface temperature is not reflected by a corresponding rise in temperature at the interior

with resultant change in heating rate, can be compensated for by watching the rate at which the metal deforms at the hot zone and modifying the weld cycle accordingly. Sometimes it is necessary to enlarge some of the heating head orifices to compensate for differences in heating rates along the interface. It is particularly easy to burn the corners of rectangular sections. Gas flow (size of flame and heat input) should be rapid enough to seal the weld promptly by plastic movement, yet not so fast as to cause undue temperature gradients and liability to burning.

It is essential that the fixtures hold the assembly in such a manner that proper pressure and alignment are maintained throughout the cycle. Fixtures must be rigid and accurately guided. They must apply pressure as nearly normal to the interface as possible. In many instances the press and the holding dies or jigs must be water cooled. Water cooling is particularly important where the jig holds the parts adjacent to the hot zone. The large amount of waste heat will invariably cause softening and thermal expansion of the fixture, and this soon results in dimensionally variable weldments. Positive stops are desirable to control the total amount of shortening and thus produce parts of close dimensional tolerance.

Many of the types of stainless steel are metastable and will change in microstructure in an undesirable way in some regions in the temperature gradient across the joint. Proper solution treatment is recommended (air cooling from an appropriate high temperature anneal) and this is particularly important for the nonstabilized types.

Inspection and Quality Control — The best quality control is based on a series of destructive tests, such as tensile, bend, impact, and microscopic, during the development of the welding cycle. These tests are then correlated with simultaneous nondestructive tests of the same welds, such as visual inspection, hot acid etch and X-ray.

Hot acid etching with 50% hydrochloric acid is a good general method of preparing welds for visual inspection. It shows cracks or localized burning. It seems to be true, invariably, that the welds are poorest around the periphery, so that X-ray and supersonic inspection rarely show anything not revealed by etching.

Most welds in stainless steels that appear sound on visual inspection after solution heat treatment will have tensile and yield strengths equivalent to those of the base material. (See Table I.) However, the elongation and reduction of area usually will be relatively low; as these values become still lower, the tensile fracture changes from the normal cup-and-cone to a modified star break, and finally to a flat break that occurs at the interface. Bend tests made on welds of the last-mentioned class will also usually crack at the interface. Flat breaks like this can be produced experimentally by using a low welding temperature, by using a low initial hydraulic pressure which permits excessive oxidation at the interface, or by using a small upset which fails to fragment and disperse the normal oxide film.

Frequently a pressure welded part may be so designed that a subsequent forging, expanding or coining operation is desirable. Such an operation then becomes an excellent proof test of the weld.

The notched-bar impact strength of a stainless steel pressure weld is never as high as the impact strength of the base material — frequently it is much lower. Preliminary data indicate that the limiting value of the fatigue strength is in the neighborhood of the transverse fatigue strength of the base material. A. B. Kinzel, in his Adams Lecture mentioned in the footnote at the outset, has the interesting theory that good endurance (by rotating cantilever beam test pieces) is to be expected from pressure welds that contain a few microscopic oxide inclusions, because the cohesive force across the bond is greater than the stress representing the fatigue limit. The present writer has no test data to disprove this idea, but it would appear that a broken-up oxide film would have the same deleterious effect as any other stress-raiser.

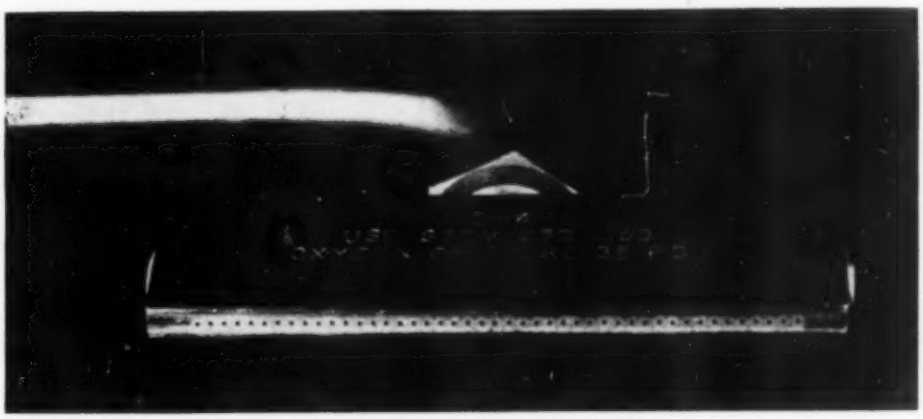

Fig. 4 — Flame Head, About Full Size

Microscopic examination of the interface, particularly after solution treatment, should show a barely discernible weld line delineated with scattered tiny oxides. There should be crystal growth completely across the interface. As the oxide film becomes continuous, the mechanical properties become lower. Figures 2 and 5 show typical structures associated with inferior and satisfactory welds, respectively. If the welding temperature is too low, the weld may be relatively free from oxides (as the result of good jigging) but grains have not grown across the weld.

Rectangular sections up to $1\frac{1}{8} \times 2\frac{3}{16}$ in. have been X-rayed and tested by supersonic waves after having been passed as satisfactory by hot acid etch inspection. No defects were indicated by these additional tests. Samples were also welded after a small daub of paint had been applied to

Fig. 5 — Microstructure of Satisfactory Weld in Type 321 Stainless Steel, Solution Treated at 1900 °F., Water Quenched. 100 ×; electrolytic NaCN etch. Note that original interface is but faintly traced with a very few oxide particles; likewise, metal has completely recrystallized across the joint

the interface before welding. X-ray and supersonic tests were still negative, but better technique may have shown the defects certainly there.

Table II gives some production results from wartime work at Wyman-Gordon Co. in the manufacture of rings from two U-shaped pieces.

Precautions — As an aid in the establishment of a welding cycle for a new assembly, the following method is suggested:

Weld several samples, while carefully controlling heat input, time, and pressure until hot acid etch shows soundness after the bead is removed. Then make bend tests, tensile tests, and micro-examinations to check weld quality. If these are satisfactory, weld and test a few additional samples using the established practice to make sure that the cycle is reproducible before proceeding with production.

The distance between the heating heads and the work must be adjusted so the temperature gradient from outside to the center of the workpiece is low enough to prevent excessive burning of the outside before the center reaches welding temperature. If the heads are too close, the outside will burn and melt, particularly after the metal becomes plastic and partial upsetting has begun. If the heads are too far away the cycle

Table II — Percentages of Good Welds

Type Stainless	Cross Section	Total Welded	Yield
347	$\frac{9}{16} \times 2\frac{3}{4}$ in.	923	97%
347	$1\frac{7}{8} \times 1\frac{7}{8}$ in.	21	100
321	$\frac{3}{4} \times 6$ in.	24	54
321	$1\frac{7}{16} \times 2\frac{5}{8}$ in.	366	60
310	$\frac{3}{4} \times 2\frac{1}{2}$ in.	313	93
310	$1\frac{1}{8} \times 2\frac{5}{8}$ in.	307	32
310	$1\frac{1}{8} \times 1\frac{7}{8}$ in.	189	90

will be longer than necessary and consequently uneconomical. For each distance, heating head to work, there is an optimum gas and oxygen flow that must be determined by trial, then carefully maintained during production. Normal proportions of acetylene and oxygen are 1 to 1, but a slight variation in flame adjustment is innocuous.

Adequate shortening or upset is particularly important when welding stainless steel because it is an effective method of dispersing the oxide film at the interface. Quantitative information on the minimum amount of upset that should be used is unavailable, but there is nothing to indicate that *too much* upset is objectionable except where it interferes with proper heating of the weld zone or where it causes mechanical difficulties with proper jigging. As an approximation, a total shortening of between ½ and ¾ in. is suggested when welding sections between ¼ and 2 in. thick.

It is generally considered necessary to clean the mating surfaces with a volatile grease solvent just before welding, but there is no published data for stainless steel showing the effect of various contaminants on weld quality. However, it has been demonstrated that fluxes, such as are normally used for gas welding stainless steel, when purposely applied to the mating surfaces do not give satisfactory welds, because a certain amount of flux is trapped at the interface and adversely affects the properties.

New Metallurgical Techniques and New Alloys of Magnesium

By J. C. McDonald
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Magnesium Division, Dow Chemical Co.
Midland, Mich.

This is the concluding part of a paper read before the Western Metal Congress. The author describes improved etchants that develop grain size and distinguish between tiny casting voids and microporosity, and also can correlate the composition, ultra-fine structure and corrosion behavior. New alloys with zirconium and especially cerium have been studied extensively; the latter have unusual strength at moderately elevated temperatures.

THE TASK of the metallographer interested in magnesium has been made easier by a number of new processes described in a recent interesting paper by P. F. George, presented to the annual convention of the ⊜ in Atlantic City in 1946. The reader should refer to 1947 *Transactions* (V. 38, p. 686) for full details. The title of the paper is "Some Special Metallographic Techniques for Magnesium Alloys". By using one of two of the new etchants one can distinguish between high and low amounts of aluminum in solid solution in the alpha magnesium phase. These etchants contain picric and acetic acids in somewhat different concentrations, and form an amorphous film on the polished surface which, when dried, cracks in a way that varies with the composition of the crystal. Figure 5 of Mr. George's paper indicates how the diffusion of aluminum from grain boundaries into the body of the crystal can be followed by this etch and at various stages of the heat treating process. The high aluminum regions where diffusion has been completed are covered by a cracked film; the central portions of the grains (after the shorter heating times) remain clear.

One of these etchants (2.5 g. of picric acid in 50 ml. ethanol, 20 ml. glacial acetic acid, and 20 ml. water) is useful to distinguish between microshrinkage and fusion voids. When microshrinkage occurs in a magnesium-aluminum-zinc alloy such as Dowmetal H (magnesium plus 6% Al, 3% Zn, 0.2% Mn) it is a characteristic of the voids that they are surrounded by the first-freezing, low-alloy material. In consequence, as shown on the left of Fig. 8,* there is none of this cracked film visible around the dark holes. With ordinary metallographic techniques a void, very like this in appearance, is sometimes observed when heat treatment has been carried out improperly. It has been difficult in the past to distinguish between these two types of defects. However, by using the new etchant it is easily seen, as on the right of Fig. 8, that a high amount of aluminum is in solid solution near these fusion voids.

Mr. George's paper also describes another new etchant which has proved extremely useful in delineating grain boundaries, either in alloys that formerly had to be specially heat treated to develop the boundaries, or in extruded or wrought, low-aluminum alloys that were hard to etch otherwise. The etchant consists of 5 g. picric acid in 100 ml. ethanol, 5 ml. of glacial acetic acid and 10 ml. of water. Freshly polished specimens are held face-up in the etchant and gently agitated for 5 sec., removed, washed in running alcohol, and dried in an air stream. It not only develops the grain boundaries in cast metal in spaces not occupied by particles of compound, but also the twins that are produced within the grains while

*Figure numbers continue from Part I.

sawing the specimen. Grains with different orientation also stain in a different way.

The electron microscope has increased our understanding of certain corrosion phenomena. In the upper left-hand corner of Fig. 9 may be seen a "fine structure" which is observed in certain magnesium-aluminum alloys when heat treated at high temperatures. In the upper right-hand corner the specimen has been aged at lower temperature with consequent precipitation of large platelets of magnesium-aluminum compound. The fine structure, however, has disappeared. A subsequent heat treatment, as shown in the lower right-hand corner, again brings out the fine structure while re-aging (observe the lower left-hand corner) again causes the fine structure to disappear with the reappearance of the magnesium-aluminum compound.

The appearance of this fine structure has been correlated with a type of corrosion observed in salt water. In Fig. 10 may be seen the correlation with aluminum content of both the photomicrographs taken optically at usual magnification, electron micrographs at much higher power, and the corrosion samples. A little aluminum (0.5%) was sufficient to create both the fine structure and the corrosion behavior which goes with it.

Zirconium and Cerium Alloys

Two alloying elements have received a great deal of attention; these are zirconium and cerium. An alloy of magnesium with zirconium and zinc has been developed which has relatively high strength properties, while retaining the toughness characteristics of the older, lower strength alloys. Magnesium alloys containing cerium have been demonstrated to possess properties at elevated temperature which would suit them for use as engine parts.

The most advantageous use of zirconium appears to be in combinations with zinc. Zirconium has a powerful effect in raising the solidus temperature of the magnesium-zinc alloys, as shown by the following figures:

Magnesium With	Solidus Temperature: No Zr	0.75% Zr Added
2% Zn	1000° F.	1140° F.
4%	840	1060
6%	730	960
7%	690	920

In consequence the zirconium-containing Mg-Zn alloys can be extruded at much higher speeds. A promising alloy, containing about 5.8% Zn and 0.80% Zr, is being developed at present entirely in the direction of making these alloys as extrusions. Not only does the zirconium have this effect but it also produces a structure in the cast billet which promotes an extremely fine grain size in the finished article which gives good combinations of properties. As is seen by the curves in Fig. 11, page 246, at least 0.50% zirconium is required to give the good effects about which we have been speaking. Figure 11 shows the actual properties obtained at two different extrusion speeds. Maximum properties are obtained at minimum speed; however, very good properties may be obtained at relatively good speeds of extrusion, as is evident from Fig. 12, page 246, to be discussed a little later.

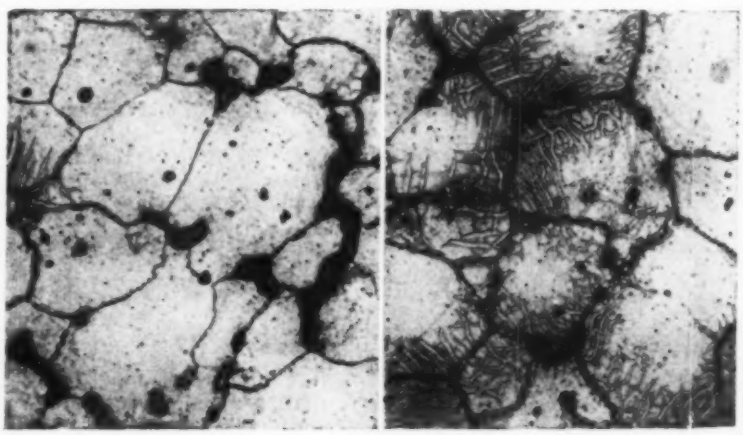


Fig. 8 — Distinction Between Microshrinkage (Left) and Fusion Voids by Cracked Film Surrounding Latter, Locating Metal Higher in Alloy Content Than Elsewhere. 100×

Table I — Toughness and Strength of Alloy With Zirconium in Comparison With Commercial Magnesium Alloys

Alloy: Nominal Composition:	ZK 60 Zn 5.0 Zr 0.75	FS-1 Al 3.0 Zn 1.0 Mn 0.3	J-1 Al 6.5 Zn 1.0 Mn 0.2	O-1 HTA Al 8.5 Zn 0.5 Mn 0.2
Rupture energy,* in-lb.	15.0	15.3	15.6	3.1
Tensile strength	49,000	37,700	42,800	52,800
Tensile yield	40,000	24,800	24,500	35,100
% Elongation in 2 in.	9.5	15.2	16.8	10.8
Compressive yield	35,000	14,700	14,900	34,400

*Slow bend of sheet specimen with side notches.

The improved toughness characteristics of the material with zirconium are shown by the figures in Table I, at left. The toughness was measured by determining the energies to rupture in

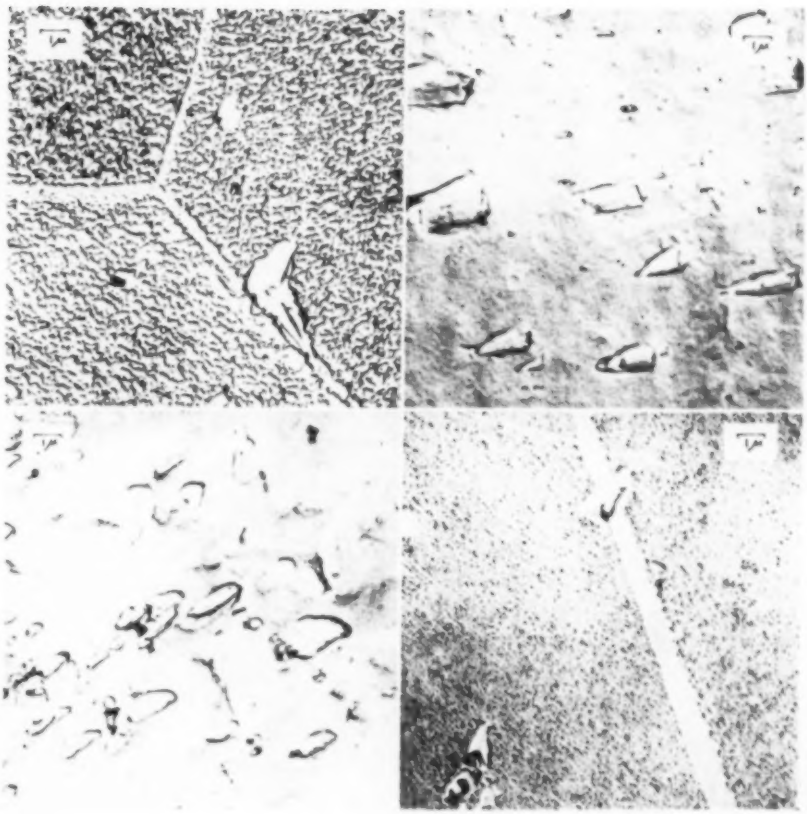
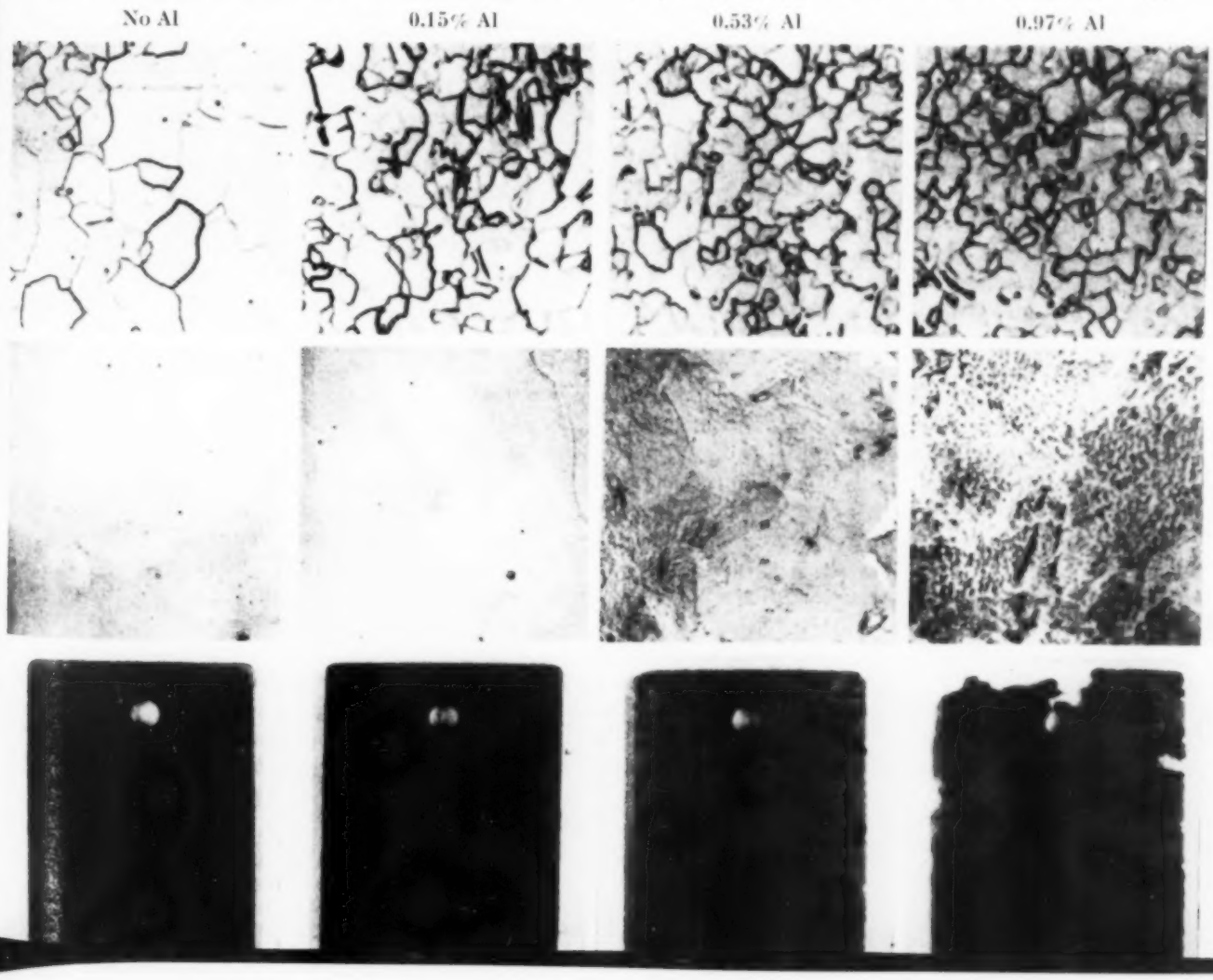


Fig. 9 (at Right) — Electron Micrographs (4000 ×) Showing Fine Structure Produced During Solution Heat Treatment in Magnesium Containing 0.50% Aluminum or More, and Its Disappearance and the Presence of Considerably Larger Mg-Al Platelets After Aging at Lower Temperatures

bending a flat sheet-type specimen with side notches. Briefly, the test consists of bending a symmetrically edge-notched, 3 x 1 x 0.062-in. specimen to failure and calculating the energy absorbed from the area under the torque versus angular deflection plot. The notch used is $\frac{1}{4}$ in. deep, $\frac{1}{4}$ in. wide at specimen edge, and V-shaped with a 0.003-in. apex radius. This gives a reduced section $\frac{1}{2}$ in. wide. Flat jaws grip the specimen $\frac{1}{8}$ in. from the minimum section and torque is applied 2 in. from this point. Although

Fig. 10 — Correlation of Salt-Water Corrosion With Aluminum Content in Pure Magnesium Binary Alloy, and With Its Microstructure (Optical, Top, at 300 × and Electron at 3500 ×)



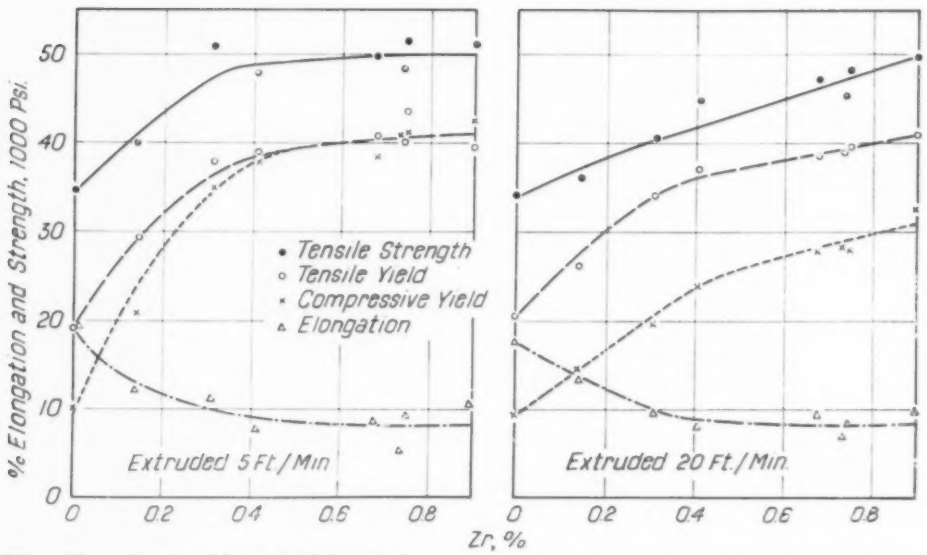


Fig. 11 — Properties of Extruded Mg-3% Zn-Zr Alloys as They Vary With Zirconium Content and With Rates of Extrusion

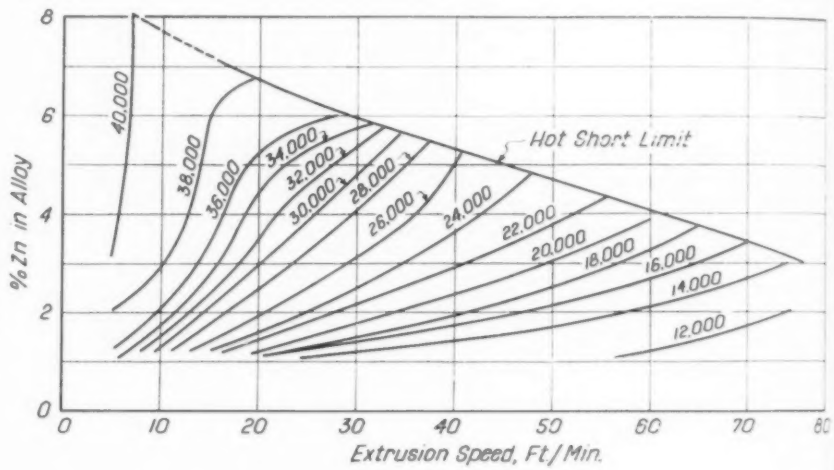


Fig. 12 — Compressive Yield Strength of Magnesium-Zinc Alloy Containing 0.75% Zr as a Function of Zinc Content and Extrusion Rate. Extruded billet 3 in. dia.; extruded strip (sheet-type test specimen) $\frac{3}{4} \times \frac{1}{16}$ in.; extrusion temperature 600° F.

the new material is not notably stronger than the older high strength material, Dowmetal O-1HTA, it is much tougher, being comparable in that respect to the lower strength alloys. This new composition is being described by its A.S.T.M. designation of ZK60.

By adjusting the zinc content in the alloys which contain more than 0.50% zirconium a wide variety of strength properties may be obtained, depending on the extrusion speed. For instance, by dropping the zinc content to 3%, material may be extruded of properties comparable to one of the older alloys such as J-1 but at much increased speeds, say 60 ft. per min. (See Fig. 12.)

The cast cerium alloys are characterized by a relatively fine grain. Manganese exerts a grain coarsening effect; the average grain size of cast magnesium with 6% cerium increasing in a linear relationship from 0.02 in. diameter with 0.6% Mn to 0.16 in. with 2.0% Mn (actual size of grains quoted). The coarser grain led to no difficulty in the foundry as long as we were making only pistons, but when we went to much larger castings a certain amount of cracking occurred which was caused by this large grain. For that reason the larger castings are being made in the binary cerium alloys, particularly the one with about 6% alloy.

Another factor influencing grain size is pouring temperature. Low pouring temperatures will give quite fine grain sizes; however, most castings will will have to be poured at temperatures above this minimum. The coarsening effect is also directly proportional to temperature. For example, in the 6% Ce, 2% Mn alloy (A.S.T.M. designation EM62) the average grain size when poured at 1200° F. is 0.02 in. (actual size), at 1300° F. is 0.05 in., at 1400 is 0.085 in., and at 1500 is 0.12 in.

The cast structure is characterized by grains of alpha magnesium solid solution entirely surrounded by a film of eutectic (alpha phase plus MgCe compound). This eutectic network is all but continuous at 1.25% Ce, entirely continuous at 2.5% Ce, and grows in thickness until about one third the field is occupied by eutectic with 10% Ce.

Such cast structure may be "stabilized" by heating, say 16 hr. at 600° F. Microstructure of the alloys after this treatment is changed only in that the homogeneous alpha grains as cast now exhibit a very fine precipitate, uniformly dispersed except for a relatively thin surface layer near the eutectic which remains clear.

The network structure can be broken up in all cerium alloys by heat treatment close to the

solidus — for example 16 hr. at 1050° F.; the action is similar to the spheroidization of cementite network in a hypereutectoid carbon steel. Little or no change in the microscopic appearance of the uniform grains of alpha magnesium solid solution (the groundmass) may be observed after this high temperature treatment, nor after a subsequent aging at 400° F. (the treatment preferred for best combination of physical properties). The fine uniform precipitate appears within the grains after aging at 600° F.

The tensile strengths of these alloys are little affected by variations in cerium content but the hardness, yield strength, and elongation are very much. As shown in Fig. 13, the composition of 6% Ce represents a compromise between maximum strength (and hardness) and minimum elongation.

Although these room temperature properties are not very high compared to other magnesium-base and aluminum-base cast alloys, they are well retained at elevated temperatures. The actual variation may be seen in Fig. 14.

The property in which the cerium alloys are really outstanding, compared to present commercial magnesium-base alloys, is in their resistance to creep. This matter was discussed at some length by A. A. Moore and the present writer before the American Society for Testing Materials in 1946 (see "Tensile and Creep Strengths of Some Magnesium-Base Alloys at Elevated Temperature", *Proceedings*, A.S.T.M., V. 46, 1946, p. 970). The creep rates are on a new order of magnitude. I cite some figures taken from that publication for creep rates at 300° F.: The forged alloy O-1HTA (8.5% Al, 0.5% Zn, 0.2% Mn) creeps at the rate of 0.7% per 1000 hr. under 4000-psi. stress, whereas forged alloy EM-22 (2% Ce, 2% Mn) creeps 0.3% per 1000 hr. under 20,000 psi. stress — less than half as much under five times the load! Put in another way, creep rates for alloy E-10HTA (90% Mg, 10% Ce) at 600° F. are on the same order as those for the old O-1HTA at 300° F.

This same effect can be seen in Fig. 15 which presents stress-rupture data (stress to produce complete rupture in various times) for the strongest of the old extrusion alloys O-1, the standard die casting alloy R, and the new Mg-Ce-Mn alloy EM-22.

New Applications

Wrought cerium-containing alloys were used in Germany during the war and their manufacture appears to offer fewer problems than do the cast alloys. Compositions are now being tried containing 1 to 2% manganese and 2 to 5% cerium, although the higher cerium contents have been preferred for "high" temperature service and were used by the Germans.

An application which is now receiving a great deal of attention is magnesium alloy sheet and plate for photo-engraving purposes. Its etching characteristics are such

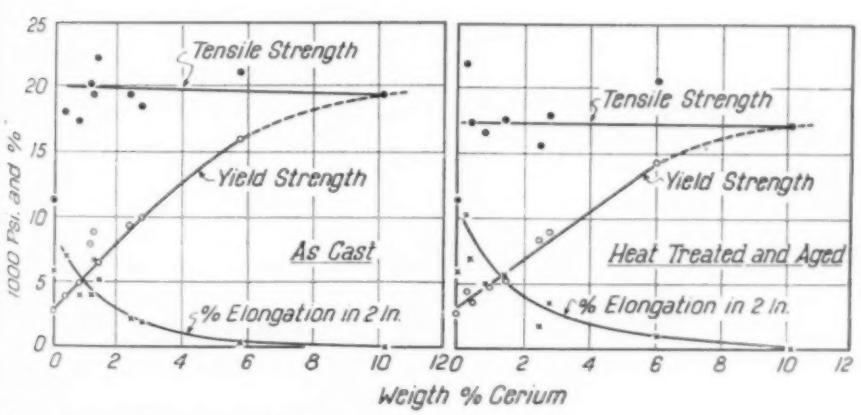


Fig. 13 — Influences of Cerium Content on Tensile Properties of Magnesium-Cerium Alloys, As Cast and Heat Treated. Heat treatment: Solution heated 16 hr. at 1050° F., air cooled, aged 16 hr. at 400° F.

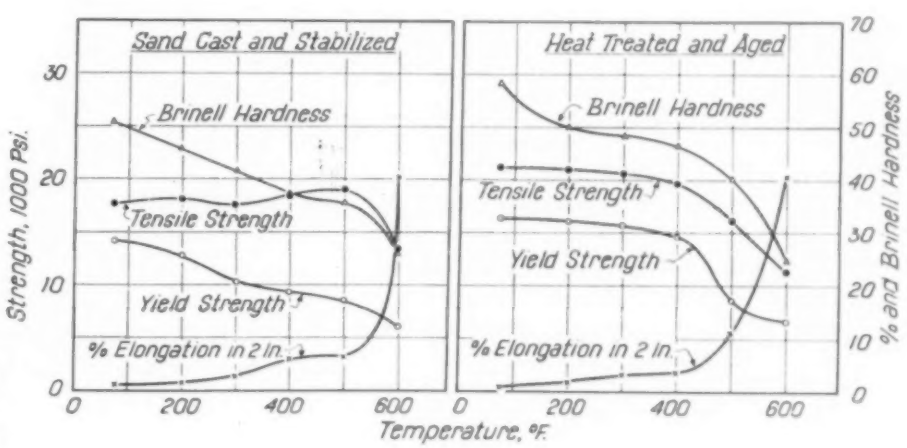


Fig. 14 — Short Time Tensile Strength and Hot Hardness of 94% Mg, 6% Ce Alloy E6 at Various Elevated Temperatures. Prior treatment: Stabilization: 16 hr. at 600° F. after casting; heat treating and aging as for samples of Fig. 13

that good reproductions are obtained. There is already a considerable market for the engraving of half-tones and for the direct reproduction of other printed material.

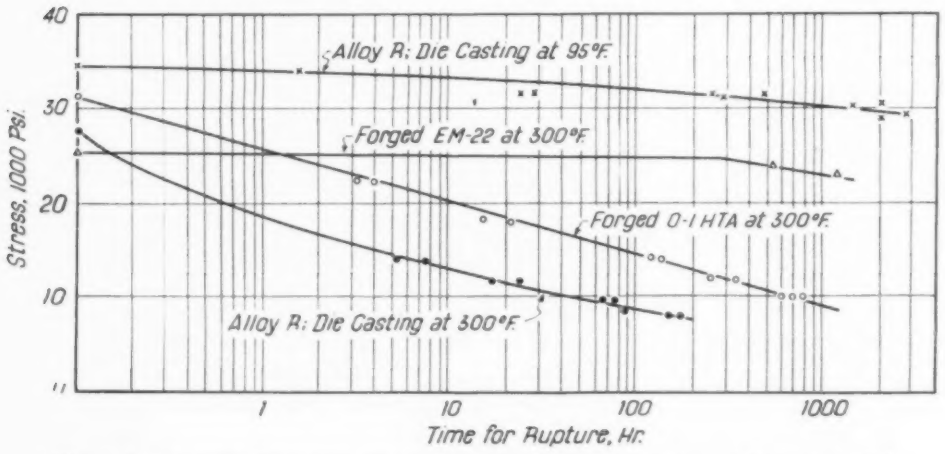


Fig. 15 — Creep-Rupture Data for Standard Extrusion Alloy O-1, Die Casting Alloy R, and 96 Mg, 2 Ce, 2 Mn Alloy EM-22, All at 300° F.

Other new uses involve some of the electrochemical characteristics of magnesium. It may be coupled as an anode to steel articles in a corrosive environment so that the electrical couple set up results in the destruction of the magnesium plate rather than the steel article. This is known as cathodic protection and is in considerable use in buried pipe lines and for hot water heaters and tankage.

Batteries, both dry and wet, constitute another potential market for magnesium. A considerable amount of experimental work is going on, directed toward the achievement of this objective.

Bits and Pieces

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Projector for Microscope Images

PROBABLY other metallurgists have met our difficulty in discussing with executives or plant personnel those failures, defective plant operations, or subgrade quality which should come to their attention and attempting to prove a point by the evidence available from microscopic examination. The person not familiar with the microscope and with metallurgical terminology can put his eye to the eyepiece, but you are never sure he is seeing the evidence which is there.

We have therefore rigged up a convenient attachment to our Bausch & Lomb metalloscope which projects the image on a small screen mounted on the optical bed. This gives a very nice image in a darkened room; several people can view the screen simultaneously and the exact spot in question can be pointed out.

The screen is an aluminum plate, painted dull white, and mounted on an appropriate clamp. One side is plain and the other has a scale (calibrated by using a stage micrometer for various fixed points on the optical stage). The green glass filter is removed, and the prism reflector used. We have found the scale very useful to demonstrate depth of carburized case, thickness of soft skin, and dimensions of gross defects. (ARTHUR R. WATSON, materials laboratory, Stromberg-Carlson Co.)

Making an Expansion Fit

USE of industrial refrigeration in making force fits has — within its present size limitations — the advantage over the conventional "shrink fits" in cleanliness (no danger of heat scale) and in handling parts too bulky for the older method. An instance in point is the placement of bushings

in the large steel casting, shown in the accompanying half-tone.

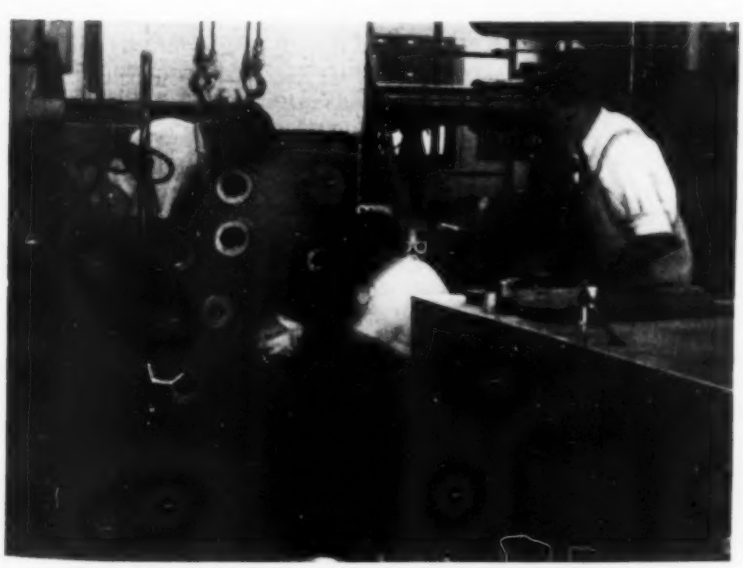
This is for a large diesel engine, and it was found that the ordinary tolerance for force fit (0.01 in. per in. of dia.) was insufficient. A 5.005-in. bushing, even when pressed into a 5.000-in. hole with strong hydraulic press, would work loose in service.

The solution to this assembly problem was to make the bushing 0.0055 in. larger than the 5-in. hole. It was then chilled to low temperature (−120° F.), contracting its diameter so it was very slightly oversize. Assembly was accomplished with a hand arbor press. (At −150° F. there would be 0.001 in. more shrink than at −120° F. which would enable this same bushing to be inserted by hand, as in the illustration.

As the part warms back to room temperature, it expands evenly so there is strong metal-to-metal bearing around its entire outer surface. Assemblies of this nature have withstood as much as 60,000 lb. pressure, tons more than any force fit would take.

The same scheme works in reverse for removing such a bushing. For example, a 12-in. dia. by 14-in. long bronze bearing was chilled enough in 5 min. to drop into place. This same part was removed in 4 min. by circulating some of the low temperature brine through a snugly fitting copper pipe placed where the shaft would be. The bearing simply dropped out.

Experience with industrial chilling to −120° F. indicated that male members could be usefully shrunk, prior to force fits, down to only about 1 or 1¼ in. in size. Use of brine at −150° F. has reduced this diameter to about ½ in. This extends the utility many fold; in the automotive industry, particularly, many small bushings and bearings are now driven into place; refrigerated, they can simply be dropped into the waiting hole. Experiment indicates that the cold brine does not affect the oil in porous bearings or bushings; the extreme cold immediately jells the oil. Cylinder liners may also be best inserted by such "expansion fits". Despite their thin walls, distortion is avoided, whereas reaming is always necessary after a mechanical press fit. (Avery C. Jones, field engineer, Bowser, Inc.)



Inserting a Chilled Bushing by Hand (Originally 0.0055 In. Oversize) in a Heavy Steel Casting for a Diesel Engine

Testing Hardness up to 700° F.

IN an investigation of the problem of die steels for molding plastics, it became apparent that economical dies could often be made by sinking a hardened steel form or punch into the warmed die block — a die sinking method often called "warm hubbing" or "warm hobbing". To make a quick survey of the steels available we wished to determine their indentation hardness at temperatures up to 700° F., and to do so without constructing some elaborate apparatus. (It is possible that the method will be even more valuable for nonferrous investigations where 700° F. represents a temperature not too far below the melting point.)

We used a Rockwell hardness machine with B indenter and flat anvil, with opening high enough to make tests on the end of a 1½-in. round, 3½ in. long. A 4-in. square of hardened ¼-in. toolsteel plate, ground to parallel surfaces, is placed on the anvil to carry the up-ended specimen and a heating unit. The latter is a fairly closely fitting tubular furnace, electrically wound, open at both ends. Testing procedure is as follows:

1. Determine the hardness of all specimens at room temperature. When starting a series of tests, retest at room temperature and compare results, thus verifying whether the indenter has been softened by previous tests at higher temperature.

2. Place the test piece within the heating element, both of them resting on another piece of ¼-in. steel plate on the bench near the Rockwell machine. The test piece should protrude from the heater about ½ in. If the first test is to be made at 150° F., scrape a little powder from a 150° F. "Tempilstik" on the top end of the steel sample, and plug

in the heating unit cord to a convenient outlet.

3. As soon as the smaller particles of "Tempilstik" begin to fuse, brush them off, and without delay slide test piece and heating element onto the steel plate protecting the testing machine anvil, and take two or three readings near the spot where the powder fused. During the time required the temperature will probably rise to 160° F.

4. Remove the test piece and its heater, and repeat above operations, using "Tempilstiks" of successively higher melting points. It will take about 40 min. to run a complete series of tests up to 600° F. The rate of heating in the simple unit we used is much slower as the temperature goes up, consequently the uncertainty of the test temperature becomes correspondingly smaller. (A. L. PRANSES, materials engineering department, Westinghouse Electric Corp.)

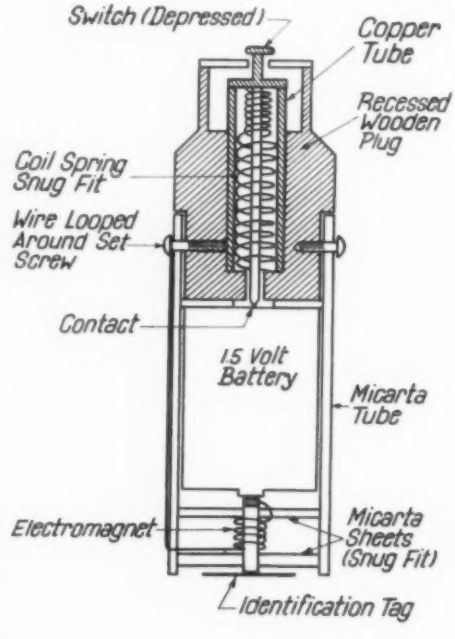
Mount Identification Tool

MANY recent articles have appeared giving methods for permanent identification of metallographic mountings — probably no two methods used by the various laboratories are identical. Faced with this same problem and not being completely satisfied with any scheme used heretofore, I decided to try an idea that was in my mind for some time.

The first thing on the list was to sort through the accumulation of miscellaneous material in our laboratory. I eventually collected the following items:

Micarta tube, 1¼ in. o.d., 1 in. i.d., 3 in. long
¼-in. machine bolt, 1 in. long
Micarta sheet, ⅛ in. thick
Spool of enameled copper wire, 28 g.
Coiled spring
Flashlight battery
Assortment of bolts, nuts and washers

Armed with this paraphernalia, I headed for the laboratory machine shop, and with the lathe and drill press, started the final assembly of the gadget (patent applied for), which might be called a magnetic pickup, positioner, and release.



This tool was made to fit the 1¼-in. mold on the Buehler mounting press, as this will handle good sized specimens and is more suitable for our work. It contains electromagnet and switch magnetism whereby the tag can be held or dropped at will. Steel tags, 0.020 x 0.875 in. diameter, were obtained from Acme Marking Equipment Co. of Detroit with a numerical and alphabetical series embossed for positive identification.

Metal samples are prepared in the usual manner, placed in the mold and covered to a sufficient depth with transparent lucite or bakelite, according to one's choice. The marking tag is placed in the recessed bottom of the holder, the switch depressed, and the marker is held in place by the self-contained electromagnet. The tool is then lowered into the mold, the switch released, the marker dropped and tool withdrawn. A small amount of transparent lucite is then used to cover the marker, and molding is finished as usual.

The accompanying sketch shows the construction. When it is necessary to replace the battery the set screws at the wire terminal and at the opposite side are removed and the upper section lifted out. (O. L. NOFTSINGER, metallurgist, Federal Machine and Welder Co.)

Distinguishing the Be-Cu Alloys

AT Eastman's Camera Works we received 134 rolls of beryllium-copper sheet, some of them having nickel and some having cobalt as a third element. Each roll was properly identified within 3 hr. with the following test:

A small clipping of metal was dissolved in a spot plate in two drops of concentrated nitric acid. When action ceased, the excess acid was neutralized with saturated ammonium acetate solution, then five drops of 20% potassium iodide solution added (to precipitate the copper) and some tiny sodium bisulphite crystals to reduce the excess iodide. The resulting milky mixture was divided in two parts.

To one was added, without stirring, four drops of the following solution: 2 g. dimethyl glyoxime in 120 ml. glacial acetic acid, to which is added 20 g. ammonium acetate in 60 ml. ammonium hydroxide. Red color indicates that nickel is present.

To the other portion was added four drops of saturated solution of ammonium thiocyanate in acetone. Blue color indicates that cobalt is present. (FRANK C. BENNETT, Jr., Eastman Kodak Co.)

Gromyko Proposes an International Commission for Atomic Energy Control

FOLLOWING the presentation of the American plan[1] for control of atomic energy to the United Nations Atomic Energy Commission, Andrei Gromyko, the Soviet representative, advanced counter-proposals[2] on June 19, 1946, which — as elaborated in later discussions — involve three international agreements ("conventions" in diplomatic jargon): First and fundamental is a convention "prohibiting atomic and other kinds of weapons of mass destruction"; second is one establishing an International Control Commission; third is one fixing quotas for atomic industries in the various nations. On December 30, 1946, the U. N. Atomic Energy Commission reported[3] to the U. N. Security Council recommending a scheme closely following the American plan, but the Russian delegate effectually vetoed its adoption on February 14, saying that the plan "cannot be accepted in any way by the Soviet Union", and by proposing various amendments.

Since the turn of the year the U. N. Atomic Energy Commission has been considering the functions of an International Control Commission, and on June 11, 1947, Mr. Gromyko proposed the following "basic provisions":[5]

1. There shall be established strict international control simultaneously over all facilities engaged in mining of atomic raw materials and in production of atomic materials and atomic energy.

2. For carrying out measures of control of atomic energy facilities, there shall be established within the framework of the Security Council an international commission for atomic energy control, to be called the International Control Commission.

3. It shall have its own inspectorial apparatus.

4. [Its organization, composition, rights and obligations] shall be determined by a special international convention on atomic energy control, which is to be concluded in accordance with the convention on the prohibition of atomic weapons.

5. [This convention] shall be based on the following fundamental provisions: *(a)* The International Control Commission shall be composed of the representatives of states which were members of the Atomic Energy Commission established by the General Assembly decision of January 24, 1946, and may create such subsidiary organs which it finds necessary for the fulfillment of its functions. *(b)* It shall establish its own rules of procedure. *(c)* Its personnel shall be selected on an international basis. *(d)* It shall periodically carry out inspection of facilities for mining of atomic raw materials, and for the production of atomic materials and atomic energy.

6. While carrying out inspection of atomic energy facilities, the International Control Commission shall undertake the following actions: *(a)* Investigate the activities of facilities for mining atomic raw materials, for the production of atomic materials and atomic energy, as well as verify their accounting. *(b)* Check existing stocks. *(c)* Study production operations to the extent necessary for the control of the use of atomic materials and atomic energy. *(d)* Observe the fulfillment of the rules of technical exploitation of the facilities prescribed by the convention on control. *(e)* Collect and analyze data on the mining and production of atomic materials. *(f)* Carry on special investigations in cases when suspicion of violations of the convention on the prohibition of atomic weapons arises. *(g)* Make recommendations to governments on the questions relating to production, stockpiling and use of atomic materials and atomic energy. *(h)* Make recommendations to the Security Council on measures for prevention and suppression in respect to violators of the conventions on the prohibition of atomic weapons and on the control of atomic energy.

7. [The International Control Commission shall have right of:] *(a)* Access to any facilities for mining, production and stockpiling of atomic raw materials and atomic materials, as well as to the facilities for the exploitation of atomic energy. *(b)* Acquaintance with the production operations to the extent necessary for the control of use of atomic materials and atomic energy. *(c)* Weighing, measurement and various analysis of atomic raw materials, atomic materials and unfinished products. *(d)* Requesting from the government of any nation, and checking of, various data and reports on the activities of atomic energy facilities. *(e)* Requesting of various explanations on the questions relating to the activities of atomic energy facilities. *(f)* Making recommendations to governments on the production and use of atomic energy. *(g)* Submitting recommendations for the consideration of the Security Council on measures in regard to violators of the conventions on the prohibition of atomic weapons and on the control of atomic energy.

8. *(a)* Scientific research activities in the field of atomic energy must comply with the necessity of carrying out the convention on the prohibition of atomic weapons and with the necessity of preventing its use for military purposes. *(b)* Signatory states to the convention on the prohibition of atomic weapons must have a right to carry on unrestricted scientific research activities in the field of atomic energy, directed toward discovery of methods of its use for peaceful purposes. *(c)* [The International Control Commission must have the facilities for carrying out scientific research activities on the use of atomic energy for peaceful purposes. In conducting this research it should insure a wide exchange of information among nations in this field, and render assistance, through advice, when requested by signatories to the convention.]

[1]Outlined in *Metal Progress*, May 1946, p. 992. [2]Outlined in *Metal Progress*, July 1946, p. 83. [3]Report outlined in *Metal Progress*, January 1947, p. 89. [4]Outlined in *Metal Progress*, March 1947, p. 444. [5]Verbatim extracts from here on, except as bracketed.

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.

Manufacture of Basic Bessemer Steel Low in Nitrogen

By Yves Dardel
Engineer
Centre de Documentation Sidérurgique
Paris, France

The basic bessemer process of steelmaking makes the most of the steel in France, Belgium, Luxemburg and the Ruhr; even in America the acid process survives for its ability to produce certain desirable qualities in steel, either uniquely or economically. Many uses are limited by the relatively high content of impurities, in comparison with openhearth or electric steels. Particularly during the war, great efforts were made in Europe to reduce the nitrogen and hydrogen content, so the basic bessemer's product could be used for heat treatable alloy steels, free from flakes in large sections. Hydrogen was controlled by drying the lime flux and blowing with dried air. This article discusses the nitrogen problem.

ABSORPTION of nitrogen by molten steel during the bessemer blow has been studied by German metallurgists for a long time, the first publication appearing in 1921. However, an accurate estimate of the solubility-temperature relationship for pure iron was not made until 1935 by the Americans Chipman, Murphy and Brick, and for the Fe-C-N and Fe-P-N systems by the German Kootz until 1941, so the respective influences of temperature and composition could not be anticipated until quite recently.

Chipman and Murphy found that the nitrogen solubility in pure iron varied from about 0.039% at 1540° C. (2800° F.) to 0.042% at 1760° C. (3200° F.). While Kootz's experimental values were a little higher, all agreed that the solubility m should obey Sieverts' law and therefore can be computed by multiplying the square root of the partial pressure of nitrogen in the gas phase p_N by a constant K, which depends only upon the absolute temperature. The general equation and its restatement with a specific value for the constant to conform with Kootz's data is shown in Fig. 1. It is seen that a considerable variation in temperature has but a small influence on solubility.

Kootz also found, from a study of melts within the range of 1600 and 1700° C., that Fe_3C and Fe_3P had the same quantitative effect on the solubility of nitrogen, namely of reducing the logarithm of m (-1.330 at 1660° C.) by 0.0092 times the weight % of either compound in the iron melted. General information about gas solubility in other metallic mixtures enables us to predict that the solubility of nitrogen in molten pig iron at a given temperature can be computed with fair accuracy from the equation of the line in Fig. 1 with the addition of a fourth term: -0.0092 (% Fe_3C + % Fe_3P). Presence of carbon and phosphorus therefore makes the logarithm of m a larger negative number, and therefore decreases the weight percent of nitrogen soluble in the iron as it increases in carbon and phosphorus.

This expanded equation, although but roughly representing equilibrium conditions, has the advantage of being valid for pig iron as well as for steel, and permits a semiquantitative discussion of the conditions necessary for the production of low-nitrogen steel.

Since a great mass of information exists about the variation in analysis of the iron during a bessemer blow, let us now compare the actual nitrogen in the hot bath with the maximum amount the metal can absorb. Representative values of the carbon, phosphorus and nitrogen, as well as temperature, as they vary with time in a bessemer blow, are shown in Fig. 2. It will be noted that temperature increases steadily from beginning to end. Silicon is not a factor in our present problem because it is eliminated at the very start. The nitrogen line in this graph has been plotted from chemical determinations of samples withdrawn from the vessel from time to time — it represents actual gas content. Therefore, it conforms to the theoretical requirements that nitrogen should be low at the beginning because temperature is low and carbon and phosphorus are high, and should be high at the end because the metal is hot and approaches the nature of pure iron.

This curve for actual nitrogen of Fig. 2 is transferred to Fig. 3, and three other curves showing the expected amount in such metal if the partial pressure of nitrogen had been lower (0.25, 0.10, and zero atmospheres) have been computed and plotted. The dotted curves in the upper part of Fig. 3 indicate that equilibrium is far from reached at any stage. These curves enable the reader to distinguish easily the effect of gas pressure from the effects of composition and temperature of the metal.

At the beginning of the refining period, the amount of nitrogen in the metal changes very slowly. If the nitrogen in the pig iron is high (say 0.008, near equilibrium) the analysis will decrease; if it is low (say 0.002 to 0.003%) it will increase — in all events rapidly attaining a value of 0.004 to 0.005%. At the drop of the carbon flame, the nitrogen has increased to but 0.008 or 0.010%. The main absorption occurs during the after-blow for eliminating phosphorus; nitrogen may reach 0.030% as shown in Fig. 2.

Nitrogen Pressure During the Blow

The composition of the gases escaping from the converter has also been determined by von Seth (*Jernkontorets Annaler*, 1924, V. 108, p. 1). During the first 2 or 3 min. the gases contain CO, CO_2, some O_2 and approximately 85% of nitrogen. In the course of carbon elimination, the proportion of CO rises to 25% while CO_2 and O_2 lower; the amount of nitrogen is then about 70 to 75%. During after-blowing, the quantity of carbon monoxide sinks again, while oxygen increases a little; the proportion of nitrogen is then about 90 to 95%, depending upon the depth and temperature of the bath. The proportion of nitrogen in the gases issuing from the mouth of the vessel varies, then, from 70 to 95%. The hydrostatic pressure of the gases passing through the molten iron is uncertain, but it will probably introduce no great error to assume that the partial pressure of nitrogen in contact with the iron remains constant and is equal to 1 atmosphere when blowing with air. In any event the amount actually in solution in the metal is far below the theoretical

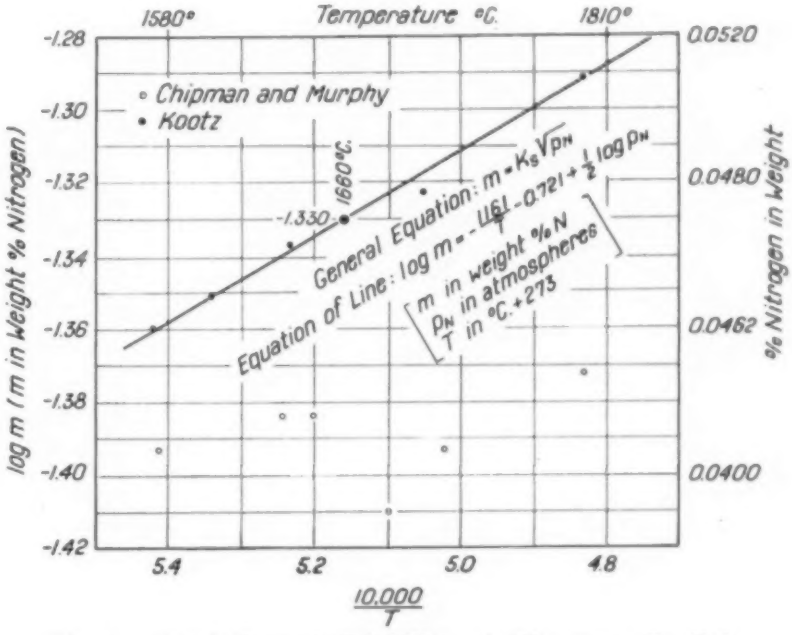


*Fig. 1 — Variation of Solubility of Nitrogen (Partial Pressure of 1 Atmosphere) in Iron With Temperature**

possibility; absorption is apparently limited by lack of time.

Kootz also estimated the kinetics of solution by studying conditions in a few grams of iron. He gives the rate of absorption as

$$\frac{d[N]}{dt} = K_1([N_m] - [N])$$

where [N] is the amount dissolved and $[N_m]$ is the amount corresponding to the partial pressure of nitrogen in the bubbling gas. Values of the differential [N] and of $([N_m] - [N])$ have been scaled from the curve representing analytical

*Authorities: Chipman and Murphy, *Transactions*, A.I.M.E., 1935, V. 116, p. 179; Kootz, *Archiv für das Eisenhüttenwesen*, 1941-1942, V. 15, p. 77.

values in Fig. 2 and 3 and plotted in the lower part of Fig. 4. The corresponding values of K_1 are also given. While the "head", $[N_m] - [N]$, reaches a maximum after 10 to 11 min. of the blow, the value of the "constant" K_1 increases rapidly clear up to the end of the after-blow, when the temperature rises from about 1500 to 1650° C. (2700 to 3000° F.).

Comparison of Fig. 3 and 4 enables one to differentiate between the influence of composition and of temperature, respectively, on nitrogen absorption. The low nitrogen content of the basic pig iron is due chiefly to its high carbon and phosphorus. As blowing starts, the amount of dissolved gas tends toward equilibrium, but the absorption is very sluggish and the discrepancy between actuality and theoretical equilibrium rapidly increases to a maximum. At this point the temperature has risen enough to speed up the solution; the K_1 values toward the end represent the ability of the iron to speedily approach equilibrium with the partial pressure of nitrogen with which it is in contact. In other words K_1 represents the bath's ability to absorb nitrogen.

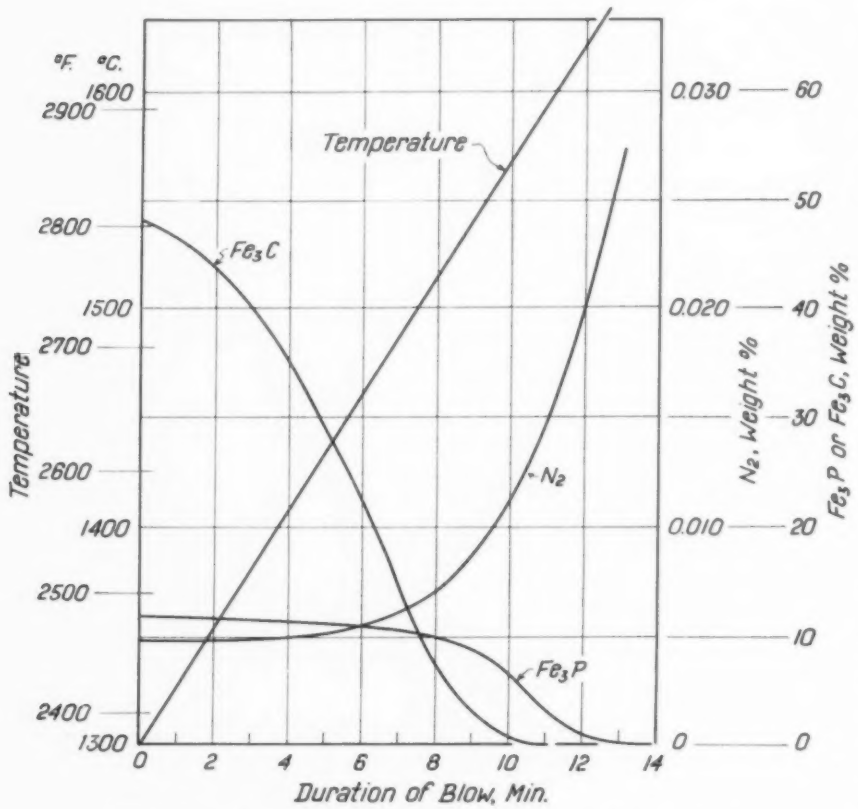


Fig. 2 — Progress of Refining of Phosphorus and Carbon During a Typical Basic Bessemer Blow, and the Rise in Temperature and Nitrogen Content

According to the differential equation given on page 253, more nitrogen will be absorbed the greater the time metal and gas are in contact. This implies that bottom-blown converters will produce steels with higher and higher nitrogen as the depth of metal in the vessel increases. The curves of Fig. 2 to 4 represent conditions for the usual deep bath where absorption is fairly important.

Other than some method of chemically purging the hot steel of nitrogen, the above discussion indicates that lower-nitrogen steel can be made by reducing the nitrogen partial pressure, reducing the temperature of the after-blow, or reducing the time of contact between metal and gas.

Krupp metallurgists, as well as Swedish (Bonthron), have suggested blowing with pure oxygen. An analysis of this proposal indicates that a bubble of oxygen passing through the bath will react with carbon to form a bubble of CO gas, into which a certain amount of the nitrogen picked up by the pig iron in its former environments will diffuse — theoretically until the partial pressures of nitrogen in metal and CO bubble are equal. Each bubble of escaping CO gas takes away a little nitrogen. Equations have been proposed for calculating the amount that can be eliminated by the time the blow is completed, but the mathematics is attended with some uncertainties. At any rate it would appear that there would be 0.001 to 0.002% nitrogen in the steel within the vessel at the end, as shown by the lower solid line of Fig. 3, if it were blown with pure oxygen. Such steel would have to be protected during pouring and teeming.

Production of low-nitrogen steel by blowing with substantially pure oxygen is quite expensive. Therefore the Brassert organization took out a French patent (No. 897,505) for the use of oxygen-enriched air — nitrogen between 10 and 30% — which can be made in quantity very much cheaper than 99.5% oxygen. Conditions during a blow with such a gas may be estimated from the solid lines in the lower right corner of Fig. 3. Metal blown with a mixture of 10% N_2 + 90% O_2 would end with about 0.010% dissolved oxygen (curve for $P_N = 0.10$ atm.), whereas it would reach about 0.014 to 0.015 if the blast contained 25% N_2 and 75% O_2.

In the last paragraph it has been assumed that the gas in contact with the steel always contained either 10 or 25% nitrogen. This would be approximately true for a 10 or a 25% nitrogen blast during the first 9 or 10 min. of the blow, but during the after-blow the proportion of the nitrogen in the gas actually in contact with the iron increases to 50% or even more, depending on the reaction of the oxygen with the iron — that is, upon the bath temperature and its depth. Nitrogen contents of such steels at finish would then, in all likelihood, be somewhat higher than indicated by the graphs.

An alternative suggested by the present author (for which a provisional patent has been issued in France) is to blow with air during the first 9 or 10 min. when absorption of nitrogen is very slow, and then use pure oxygen in the after-blow. Due to the speed of the reactions with pure oxygen this will take only 1 min. at most, and the dissolved nitrogen (as shown by the appropriate curve at the lower right of Fig. 3) drops to 0.003 to 0.005%, a value which is about equal to the content of openhearth steel.

Another scheme was used in the Ruhr during the war — or at least was described as practicable to investigators for the allied army's Combined Intelligence Objectives Subcommittee. The air blast was stopped near the end of the carbon flame and iron ore of first class quality put into the vessel. The oxygen of the ore will react with the remaining carbon and the phosphorus. Since the nitrogen content of the hematite is only 0.003 to 0.005%, the large addition of nitrogen from air at the end is avoided. It is also claimed that the cooling of the bath acts in the same direction; however, the drop in temperature is a disadvantage because it slows down the transfer of the nitrogen *from* the metal to the low-nitrogen ore and reaction products. Consequently, a supplementary blow of 1 or 2 min. is recommended after the ore has been well absorbed, in order to raise the temperature.

Actual data from this practice are unknown to the writer, and he sees no way of computing the nitrogen transfer. It is certain that the results will depend on the temperature of the ore at the time it is added, its screen size and its physical condition. Even the best of ore adds the impurities of its gangue to the bath; rolling mill scale would be far preferable but sufficient quantities would never be obtainable.

The same document about enemy practices indicates that bath temperature was lowered in some bessemer plants by adding scrap steel of proper size and amount to the vessel just before the after-blow starts.

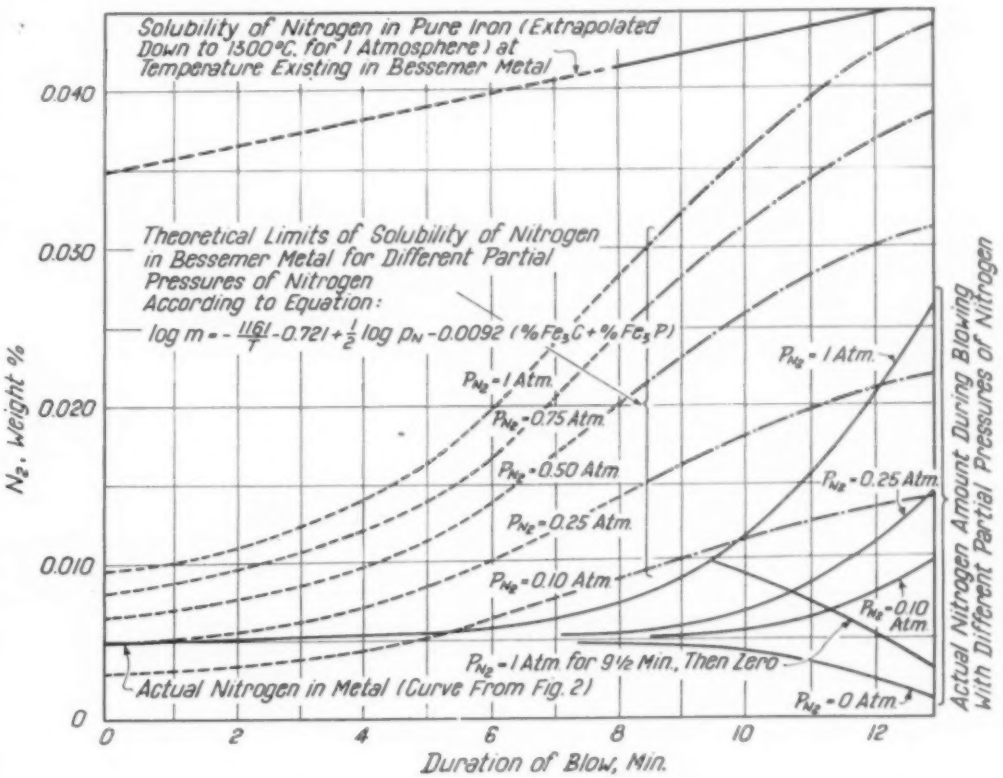

Solubility of Nitrogen in Pure Iron (Extrapolated Down to 1300°C. for 1 Atmosphere) at Temperature Existing in Bessemer Metal
Theoretical Limits of Solubility of Nitrogen in Bessemer Metal for Different Partial Pressures of Nitrogen According to Equation:
log m = -1161/T - 0.721 + 1/2 log p_N - 0.0092 (%Fe3C + %Fe3P)
P_N2 = 1 Atm.
P_N2 = 0.75 Atm.
P_N2 = 0.50 Atm.
P_N2 = 0.25 Atm.
P_N2 = 0.10 Atm.
P_N2 = 1 Atm.
P_N2 = 0.25 Atm.
P_N2 = 0.10 Atm.
P_N2 = 1 Atm. for 9½ Min., Then Zero
P_N2 = 0 Atm.
Actual Nitrogen in Metal (Curve From Fig. 2)
N2, Weight %
0.040
0.030
0.020
0.010
0
0
2
4
6
8
10
12
Duration of Blow, Min.
Actual Nitrogen Amount During Blowing With Different Partial Pressures of Nitrogen

Fig. 3 — Variation of Nitrogen During Blow With Air and Derived Curves for Lower Pressures of Nitrogen and for Equilibrium Conditions

Advantages of a Shallow Bath

Likewise, there are possibilities in modifying the time of contact between atmospheric nitrogen and the hot metal, either by blowing a shallow bath, or by using a side-blown converter. If the converter is the standard bottom-blown vessel and low-nitrogen is desired, the amount of liquid pig iron charged would be reduced by 25%, thus

creating a pool 24 in. deep instead of the usual 32 in. German metallurgists informed the Army's interrogators that when using such a shallow bath plus cooling with steel or with iron ore, or blowing a shallow bath with oxygen-enriched air, steel was produced containing less than 0.010% nitrogen. Optimum conditions for any such program must be determined by cut-and-try methods.

While the author can present no data about nitrogen content in steels from the side-blown Thomas converter, it is reasonable to presume that they would generally be similar to the good results obtained with side-blown vessels with acid lining, used for converting low-phosphorus pig iron. Contact between nitrogen in the blast and the metal in the bath is very good in a bottom-blown vessel; the speed of absorption at the high temperature near the finish approaches the reaction speed. In a side-blown converter, however, the greater part of the nitrogen that gets into the bath must diffuse downward from the upper layers which are in intimate contact with the stream of air. Since speed of diffusion is very much lower than the reaction speed, steel from the side-blown converter should be not much higher in nitrogen than the pig iron from which it was made. (Decarburization in such a vessel is also limited by the speed of oxygen diffusion, but as soon as oxygen reacts with carbon it forms a gas and this escapes continuously. Consequently the oxygen in the metal is always low during the blow, the speed of diffusion from the rich top layers is much greater than it is for nitrogen, and the time to complete the refining is not too long extended.)

Precipitating Nitrogen With Alloys

One other possibility yet remains — to decompose iron nitride in the finished steel by proper additions of an element with strong affinity for nitrogen. Aluminum, titanium and zirconium have been suggested for this purpose — in fact, we understand that ferro-zirconium is a preferred addition in America for the production of nonaging soft steels and for those low-alloy steels which must have superior toughness at subzero temperatures.

The present author has investigated the thermochemistry and the dynamics of the reactions between iron nitride, aluminum and oxygen. Iron nitride will be reduced through an addition of aluminum, but the aluminum nitride will be converted to Al_2O_3 and N_2 immediately on coming in contact with the blast. Therefore the only aluminum nitride that is eliminated from the steel is that which is wetted by the slag, and this is the reason why the denitriding action of aluminum is so small.

In summary, it may be said that the physico-chemistry and metallurgy of nitrogen in the bessemer process are well enough known so that sound predictions can be made as to the proper procedure for the production of low-nitrogen Thomas steel, other than by neutralizing nitrogen with ferro-alloy additions.

Nitrogen is bound to be higher in normal basic (Thomas) steel than in the normal acid steel made in America, since the most of the nitrogen is absorbed in the after-blow which eliminates phosphorus from the basic steel. Basic bessemer steel containing less than 0.005% N_2 can be produced by using oxygen of commercial purity during the after-blow (which thereby is shortened to about 1 min.). Steel containing about 0.010% N_2 can be produced by using oxygen of 90% purity for the entire blow. About the same nitrogen content may be had by blowing an under-weight heat, and cooling the metal with scrap or iron ore after the carbon flame drops and before beginning the after-blow. The side-blown converter also has good (though unexplored) possibilities.

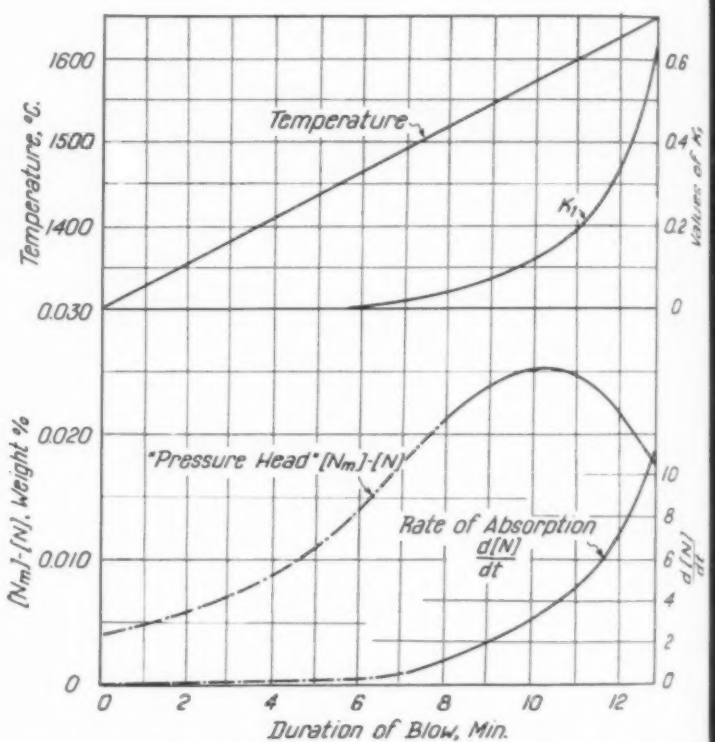
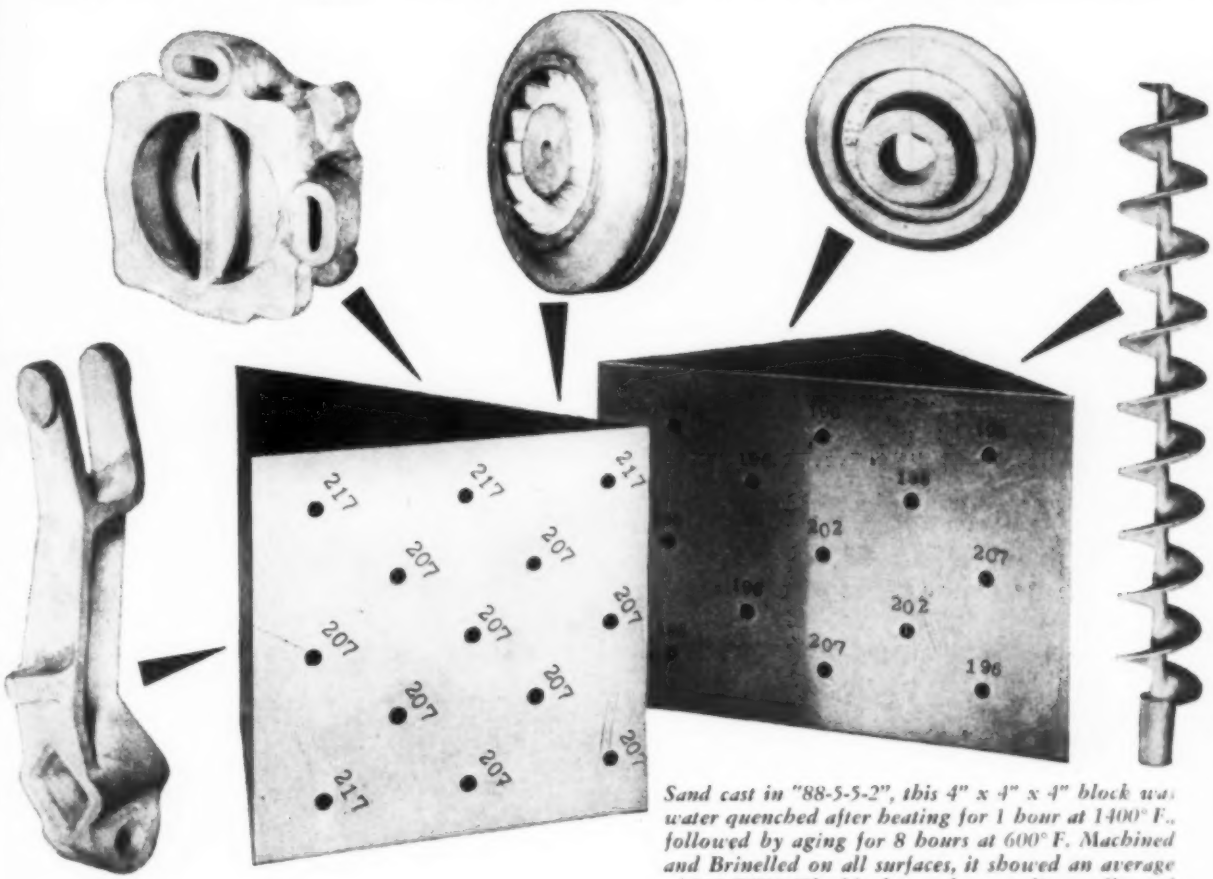


Fig. 4 — Variation of Rate of Nitrogen Absorption, "Pressure Head", and K_1 With Temperature During the Blow

AN AGE-HARDENABLE

NICKEL-BRONZE

DEVELOPED FOR HEAVY DUTY SERVICE



Sand cast in "88-5-5-2", this 4" x 4" x 4" block was water quenched after heating for 1 hour at 1400° F., followed by aging for 8 hours at 600° F. Machined and Brinelled on all surfaces, it showed an average of 209 BHN. The block was then cut diagonally, and both interior surfaces averaged 197 BHN.

Specify "88-5-5-2" (Copper-Tin-Nickel-Zinc) where you want corrosion-resistant bronze castings with extremely high mechanical properties.

This alloy in the "as-cast" condition serves the same purposes as "G" Bronze, but that's not the whole story.

The excellent physical properties of "88-5-5-2" may be immensely improved by heat treating . . . as exemplified by the block shown above.

The Nickel content provides the age-hardening response which increases both tensile and compressive strength, being particularly effective in raising the elastic properties. Nickel also increases fluidity in the casting mixture, thus affording a widened casting range that helps to minimize misruns and improves density and pressure-tightness.

This age-hardening Nickel-bronze meets wide demands. Philadelphia Bronze and Brass Corp., maker of the parts illustrated, produces "88-5-5-2" castings that range in size from ½" x 12" bars to parts weighing over 500 pounds.

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THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Classification of Prepared Atmospheres

By C. C. Eeles and M. E. Shriner

(From American Gas Assoc., Industrial and Commercial Gas Section, Information Letter No. 9)

Class	Method of Preparation	Air to Gas Ratio (a)	Analysis, By Volume (a)					Dew Point, °F.	Fuel Gas Req'd (c)	Cost (d)	Nature of Atmosphere
			N_2	CO (b)	CO_2	H_2 (b)	CH_4				
Exothermic Base — Combustion of gas-air mixture. This may be followed by cold water, refrigeration or absorbent tower dehydration, depending on desired dew point.											
101	Exothermic base with lean mixture	9.0	86.8	1.5	10.5	1.2	—	(e)	120	0.070	Noncombustible; slightly reducing
102	Exothermic base with rich mixture	6.0	71.5	10.5	5.0	12.5	0.5	(e)	155	0.085	Combustible; toxic; medium reducing
103	Class 101 prepared directly in the furnace										
104	Class 102 prepared directly in the furnace										
105	Class 101 followed by passage through incandescent charcoal		77.8	20.1		2.1					Combustible; toxic; very reducing
106	Class 102 followed by passage through incandescent charcoal		67.3	19.3		12.9	0.5				Combustible; toxic; very reducing
112	Class 102 plus combusted mixture of chlorine, hydrocarbon fuel gas and air										
113	Class 101 with sulphur removed										
114	Class 102 with sulphur removed										
116	Class 102 carrying lithium vapor (red-line cartridge)										
118	Class 102 carrying lithium vapor (blue-line cartridge)										
Prepared Nitrogen Base — Exothermic base followed by removal of carbon dioxide and water vapor.											
201	Prepared nitrogen base with lean mixture	9.0	97.1	1.7	—	1.2	—	−40	135	0.100	Noncombustible; inert
202	Prepared nitrogen base with rich mixture	6.0	75.3	11.0		13.2	0.5	−40	160	0.120	Combustible; toxic; medium reducing
207	Class 201 plus raw hydrocarbon fuel gas										
208	Class 202 plus raw hydrocarbon fuel gas										
213	Class 201 with sulphur and odors removed										
214	Class 202 with sulphur and odors removed										
Endothermic Base — Gas-air mixture reacted in catalyst-filled externally heated chamber.											
301	Endothermic base partially reacted and quick cooled to eliminate breakdown of CO into $C + CO_2$	2.6	45.1	19.6	0.4	34.6	0.3	+50	190 (f)	0.230	Combustible; toxic; very reducing
302	Endothermic base completely reacted and cooled as in Class 301	2.5	39.8	20.7	—	38.7	0.8	0 to −5	200 (f)	0.230	Combustible; toxic; very reducing
305	Class 301 followed by passage through incandescent charcoal										
307	Class 301 plus raw hydrocarbon fuel gas										
308	Class 302 plus raw hydrocarbon fuel gas										
309	Class 301 plus raw hydrocarbon fuel gas and raw ammonia										
310	Class 302 plus raw hydrocarbon fuel gas and raw ammonia										
315	Class 301 carrying lithium vapor (white-line cartridge)										
Charcoal Base — Air passed through charcoal-filled vertical retort externally heated; prepared gas drawn off at maximum temperature zone. Undesirable constituents of green charcoal eliminated by venting small portion of the gas formed at top.											
402	Charcoal base		64.1	34.7	—	1.2	—	−20	12.5 lb. charcoal	0.430	Combustible; toxic; extremely reducing
408	Class 402 plus raw hydrocarbon fuel gas										
410	Class 402 plus raw hydrocarbon fuel gas and raw ammonia										
421	Air plus ammonia and benzol passed through incandescent charcoal without external heating		63.0	33.5	1.0	2.0	0.5	−10	16.0 lb. charcoal	0.430	Combustible; toxic; extremely reducing
Ammonia Base —											
500	Ammonia, raw										
501	Ammonia dissociated in externally heated chamber	No Air	25.0	—	—	75.0	—	−60	23.5 lb. ammonia	2.00	Combustible; reducing
521	Class 501, nearly completely burned, followed by water, refrigeration or absorbent tower dehydration depending on desired dew point	1.9	99.0	—	—	1.0	—	(e)	13.7 lb. ammonia	1.20	Noncombustible; inert
522	Class 501, partially burned, followed by water, refrigeration or absorbent tower dehydration depending on desired dew point	1.3	80.0	—	—	20.0	—	(e)	14.9 lb. ammonia	1.30	Combustible; slightly reducing

(a) Analyses based on 1000-B.t.u. natural gas requiring 9.6 volumes of air for complete combustion. For other gases multiply "air to gas" ratio quoted by 0.5 for artificial gas high in hydrogen; by 0.4 for artificial gas with medium H_2, high CO; by 2.5 for propane; by 3.2 for butane.

(b) If made with artificial gas, the CO will be slightly lower and H_2 somewhat higher. With propane and butane the reverse will be true.

(c) "Fuel gas required" represents the cu.ft. of 1000-B.t.u. natural gas required to make 1000 cu.ft. of atmosphere. For other fuel gases multiply by 2.0 for high H_2 artificial gas; 2.5 for medium H_2, high CO artificial gas; 0.4 for propane; 0.3 for butane.

(d) Costs (in dollars per 1000 cu.ft. of atmosphere) are based on: Natural gas at 40¢ per 1000 cu.ft.; electricity at 1¢ per kw-hr.; water at 6¢ per 1000 gal.; charcoal at 2½¢ per lb.; ammonia at 7¢ per lb. Amortization not included.

(e) Room temperature (cooling by tap water). May be reduced to +40° F. by a refrigeration unit, or to −30° F. by absorbents.

(f) Plus 250 cu.ft. of fuel gas for heating retort per 1000 cu.ft. of prepared atmosphere.

Boron in Steel

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The report by Robert S. Archer, published in the October 1946 issue, summarized the state of knowledge concerning the use of boron in steel as it existed in late 1942. Substitution of boron — a very common element — for strategic alloys appeared attractive because of the relatively small amount of boron necessary to increase hardenability equivalent to that obtained with much larger amounts of the ordinary alloying elements such as manganese, chromium, nickel, and molybdenum. It is not surprising, then, that many investigations were instituted and financed by various government and private agencies. It is the purpose of the present paper to summarize the results of some of these investigations.

ONE DIFFICULTY metallurgists were facing in 1942 was the lack of a reliable method of chemical analysis for boron in steel in the low range (<0.01% boron) encountered when the amounts necessary to give optimum hardenability were added to steel. Since then, however, both chemical and spectrographic methods, which can accurately determine these small amounts of boron in steel, have been developed. Dean and Silkes, in a recent Bureau of Mines Information Circular (No. 7363), reviewed the available methods of analysis. They list the colorimetric method of the Youngstown Sheet and Tube Co. as the most accurate, with a reported accuracy of ±0.0002%. This method involves the use of quinalizarin as the color-producing agent. In Battelle's analytical laboratory, the Youngstown Sheet and Tube method is used for boron percentages of less than 0.01. For amounts greater than 0.01%, the Hague and Bright distillation and titration method is used with estimated accuracies of ±0.002%. The use of quartzware is recommended for both methods to prevent the pickup of boron from ordinary glassware.

Spectrographic standard samples have been issued by the National Bureau of Standards. They cover the range from 0.0006 to 0.019% boron. Determination of as low as 0.0001% boron spectrographically has been reported by the Bureau, when a direct current arc, to which sodium was added to suppress an interfering iron line, was used.

In addition to the spectrographic standards, a chemical standard containing 0.0027% boron is available from the Bureau of Standards.

Accurate as the methods of analysis have become, it has been impossible to obtain a satisfactory correlation between the boron content and the hardenability of steels. Nor is the correlation any better when soluble or insoluble (in sulphuric or phosphoric acids) boron contents are considered.

R. A. Grange, at United States Steel Corp.'s research laboratory, has developed a technique for detecting boron-treated steels by metallographic means. A specimen is heated to 2000° F., cooled to a temperature just below A_1, held there for one hour, and then cooled. With this treatment for hypo-eutectoid steels, ferrite comes out in the austenite grain boundaries and the boron constituent, variously reported by other investigators to be $Fe_2B \cdot Fe_3C$ or BN_2, precipitates in the ferrite background. With increasing boron content, the precipitate graduates from a series of dots to a more-or-less complete film along the grain boundaries, thus affording a semiquantitative method of estimating the amount of effective (for producing hardenability) boron present in steel. Figure 1, taken from Grange's paper, illustrates this graduation. The author finds better correlation between hardenability and metallographically determined

No Boron 0.0006% 0.0008% 0.0014%

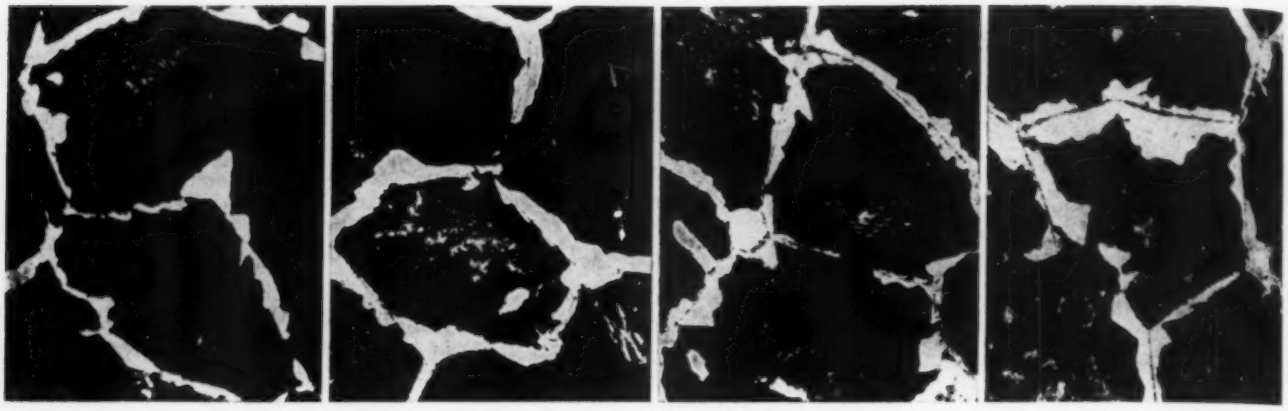


Fig. 1 — Grange's Metallographic Test for Boron Constituent at Grain Boundaries. 500 ×

boron than between hardenability and chemically determined boron. However, neither chemically nor metallographically determined boron is entirely adequate for predicting hardenability; the two methods supplement each other and are important aids in studying the effects of boron in steel and the mechanism of these effects.

Grange and Garvey have found that high austenitizing temperatures for certain boron-treated steels have the effect of decreasing their hardenability to below that of similar steels without boron, but the normal effect of boron was regained by normalizing at ordinary temperatures. However, lengthy high-temperature treatments eliminated completely the boron effect on hardenability and the boron microconstituent disappeared. Boron-treated steels which show complete loss of the boron effect in as little as 24 hr. at 2350° F. are the exception rather than the rule among commercial heats, but no steels have been encountered which do not show some loss in hardenability when such heating is extended somewhat beyond 24 hr. However, it appears that appreciable loss in hardenability will seldom result from ordinary commercial processing. The type of alloy used to make the boron addition may influence the degree to which hardenability is lost at high temperatures; further investigation of this possibility is desirable.

Methods for Adding Boron

A number of boron-containing alloys are now available for introducing the element into steel. Table I, taken with slight modifications from the publication of Dean and Silkes, lists these alloys together with their nominal compositions. These authors discuss the alloys in some detail.

Of these agents, the boron trioxide and the Pyrobor have not been used as additions — other

Table I — Addition Agents Containing Boron

Name	Reported Composition, %										Producer
	B	Ti	V	Zr	Al	Si	Mn	C	Fe	Other	
Silvaz No. 3	0.55-0.75	9-11	9-11	5-7	5-7	35-40	...	...	Balance	...	Electro Metallurgical Co.
Silcaz No. 3	0.55-0.75	9-11	...	3-5	6-8	35-40	...	...	Balance	9-11 Ca	Electro Metallurgical Co.
Bortam	1.5 -1.9	16-18	...	...	13-15	20-22	21-24	<1	Balance	...	Titanium Alloy Mfg. Co.
Carbortam	0.90-1.15	15-17	...	...	1-2	2.5-3.0	0.1-0.2	6.5-7.5	Balance	0.10-0.20 Cr	Titanium Alloy Mfg. Co.
Borosil	3-4	...	...	...	...	40	...	...	Balance	...	Ohio Ferro Alloys Co.
Manganese-boron	15-20	...	...	...	...	<1.5	Balance	<3	<5	...	Electro Metallurgical Co.
Nickel-boron	15-18	...	...	...	<1	<1.5	...	<0.5	<3.0	Balance Ni	Electro Metallurgical Co.
Grainal No. 79	0.5	20	...	4	13	...	8	...	Balance	...	Vanadium Corp. of America
Grainal No. 1	0.2	15	25	...	10	...	...	...	Balance	...	
Grainal No. 6	0.2	20	13	...	12	...	...	...	Balance	...	
Ferroboron	10-14	...	...	...	...	4	...	<3	Balance	...	Molybdenum Corp. of America
Fused boron trioxide glass	31	...	...	...	...	...	...	...	...	99 B_2O_3	
Pyrobor	22	...	...	...	...	...	...	...	...	100 $Na_2B_4O_7$	
Boron carbide	80	...	...	...	...	...	...	...	...	100 B_4C	Norton Co.

than experimentally — and probably will not be, despite their advantage of low cost. The reason for their unpopularity is that there is much variation in the "recovery" when they are used, and the ever-present danger of hot shortness when overdosing the steel with boron.

Likewise, manganese-boron, nickel-boron, and boron carbide have not been extensively tried other than for experimental heats. Their use will probably be restricted to special heats. Boron carbide, by itself, because of its high boron and the resulting small sized addition, would be difficult to use.

Much controversy has ranged over the relative effectiveness of ferroboron and some of the other special addition agents listed in Table I. One advantage of the special agents is the somewhat larger size of the addition, resulting from their lower content of boron. This larger addition is especially advantageous where it is being made in the mold, because of the greater ease with which it can be spread out during the entire pour. An addition of boron, in any form, is by no means a corrective for poor steel-melting practice. It has been substantiated by almost all investigators in the field that to obtain optimum and reproducible results, it is essential that the steel be fully deoxidized before the addition is made. Udy and Rosenthal point out that full deoxidation is necessary when the intensifier alloys, such as Silcaz or Grainal, are used. These investigators found equally good results with ferroboron as with the special alloys. This was also the experience of Corbett and Williams at the Bureau of Mines, although they were working with silicon-killed steels.

An S.A.E. Technical Board report compiled by Buswell, Danse, and McGrath and dated August 2, 1946, describes a cooperative Ordnance project on the investigation of boron-treated steel. Each of 31 of the 32 ingots from a 130-ton basic openhearth heat of 0.43% carbon, 1.60% manganese steel was treated with one of the following commercial boron alloys: Silcaz No. 3, Grainal No. 79, Grainal No. 1, ferroboron, Bortam, Silvaz No. 3, and Borosil. Conclusions were that these agents, when added in the more favorable amounts, were substantially equally effective in improving the properties of this steel. Some slight advantage was shown for the special agents in counteracting grain coarsening which accompanied ferroboron and Borosil additions. (Grain coarsening has also been noted by other investigators, although Corbett and Williams report none with boron additions.)

It was suggested during the discussion of the paper by Grange and Garvey that the disappearance of the effective boron on lengthy high-temperature heatings might be less if special addition agents were used rather than ferroboron, but this has not been substantiated.

Digges and his coworkers at the National Bureau of Standards added boron to steels of a base composition of 0.3% carbon, 1.60% manganese by means of ferroboron, Grainal No. 79, Silcaz No. 3, and a synthetic mix similar in chemical composition to Grainal No. 79. The hardenability of the steels made with the synthetic alloy compared favorably with that of the steels made with Grainal No. 79.

Table II — Summary of S.A.E. Technical Board's Work

Additions				Boron Analysis of Steel	J-50 Hardenability; 1/16 In.
Agent	Lb. per Ton	Boron Added	Aluminum		
Silcaz No. 3	5	0.0011%		0.0012	13.5
Silcaz No. 3	7	0.0015		0.0021	15.3
Silcaz No. 3	10	0.0022		0.0035	14.0
Grainal No. 79	2	0.0006		0.0005	12.7
Grainal No. 79	4	0.0013		0.0008	12.7
Grainal No. 79	6	0.0019		0.0018	13.0
Ferroboron	0.34	0.0020	0.25%	0.0021	13.0
Ferroboron	0.52	0.0030	0.25	0.0026	13.2
Ferroboron	0.69	0.0040	0.25	0.0039	13.2
Bortam	2	0.0013		0.0015	12.8
Bortam	4	0.0027		0.0027	14.2
Bortam	6	0.0040		0.0035	14.2
Grainal No. 1	2	0.0004		0.0001	11.4
Grainal No. 1	4	0.0008		0.0003	16.1
Grainal No. 1	6	0.0011		0.0007	15.0
Silvaz No. 3	2	0.0005		0.0007	12.0
Silvaz No. 3	4	0.0010		0.0008	16.0
Silvaz No. 3	6	0.0016		0.0013	17.5
Borosil	1.5	0.0019	0.25	0.0016	12.5
Borosil	2.9	0.0036	0.25	0.0020	13.2

Boron additions are most generally made in the ladle, although occasionally additions have been made to the molds. Fading of the boron effect in the last ingots of a pour has been reported, but this is probably a result of poor steelmaking practice, and will not occur when the boron addition is sufficiently protected with aluminum.

Desirable Size of Additions

There is relatively good agreement among all of the investigators as to the desirable size of boron additions to steel. In the work reported by Buswell, Danse, and McGrath, additions were made as shown in Table II.

After all these additions the hardenability (of a 0.45% carbon, 1.50% manganese steel) was improved, but no definite correlation was obtained between the degree of hardenability and the amount of boron retained in the steel or the composition of the agent used to add the boron.

Grossmann showed that the "multiplying factor" for boron increased up to about 0.0025% added boron and then decreased somewhat. Crafts and Lamont find an increasing multiplying factor for added boron up to about 0.001%, with a steady value for higher boron contents. Their published data for these higher boron contents are rather meager, so their reported steady value can probably be discounted in view of its disagreement with the work of other investigators. Corbett and Williams show a maximum in the multiplying factor at slightly over 0.002% total boron, while Udy and Rosenthal show a maximum multiplying factor for the steels they studied at 0.0015 to 0.002% added.

In the previously mentioned work of Digges, the amount of boron added to their steels for maximum hardenability varied with the composition of the ferro-alloy used for making the additions and, to some extent, with the degree of deoxidation at the time of making the addition.

In some work with some aluminum-killed steels containing 0.3% carbon and varying amounts of manganese, chromium, and molybdenum, Digges reported the following:

> "The hardenability of many of the experimental steels prepared in an induction furnace and of all the steels comprising a basic openhearth steel were markedly improved by additions of boron. . . . In many of the experimental steels, the optimum hardenability was obtained with small additions of boron (0.001% or less) while in other steels the hardenability increased continually with increase in boron. In other steels, the addition of boron, either as a single or complex ferro-alloy, was without effect on hardenability. In general, small additions were more effective than large, while complex alloys were more effective than the simple ones, and the improvement in hardenability was not so critically dependent upon the amount present when the additions were made with the complex alloys as with the simple ones."

Tisdale, of Molybdenum Corp. of America, in his discussion of the paper by Grange and Garvey, stated that above 0.0015% the proportional effect diminishes, but nevertheless still goes on until 0.0025% is reached. Actually, there is an effect of increased hardenability at still higher percentages of added boron up to, at least, the limiting content with respect to hot shortness, which is believed to be 0.006 to 0.007% — a limit which has not changed from that mentioned in the 1942 report by Archer.

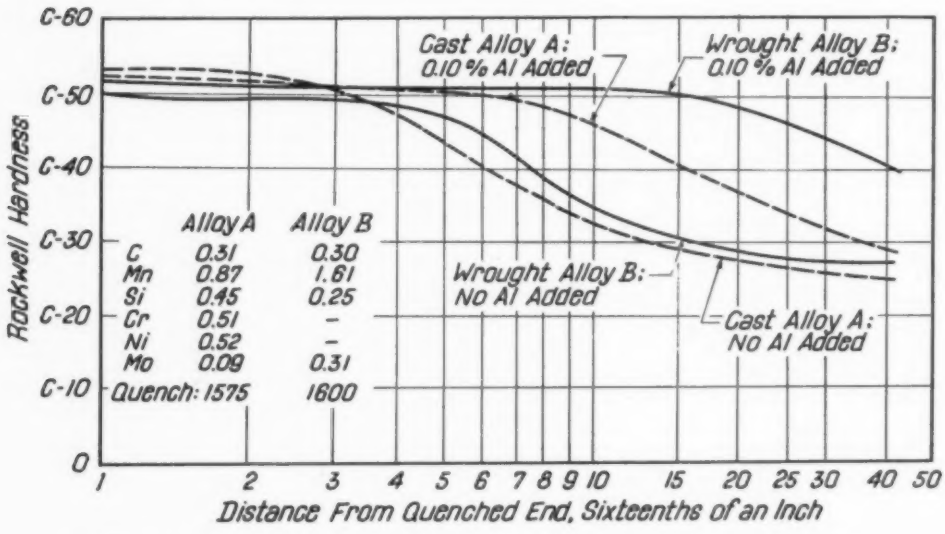


Fig. 2 — End-Quench Hardenability Curves for Wrought and Cast Boron-Treated Steels Showing Effects of Aluminum Addition Prior to 0.002% Boron Addition. (Udy and Rosenthal)

Udy and Rosenthal's studies on cast steels show that a 0.0015% boron addition produced a maximum depth of hardening, and that higher additions (0.003 and 0.006%) caused less hardening depths than the maximum — yet, at the same time, the hardness of the quenched end of an end-quench bar of a steel containing the higher boron was increased by about 5 points on the Rockwell C-scale. No explanation of this phenomenon could be found.

The limits reported above are based on tests of fully killed steels (with the exception of those by Corbett and Williams). Naturally, if part of the boron in the addition were used for deoxidation, these limits would necessarily be higher. Such a practice, however, would be conducive to erratic hardenability results and would possibly lead to occasional heats which would be hot short — or, at least, lacking in ductility.

Udy and Rosenthal have published end-quench curves showing the benefits of aluminum deoxidation with steels with recommended amounts of Grainal No. 79 and Silcaz No. 3 as compared to the same types of steels that were silicon killed. These are reproduced in Fig. 2. They also tested

three steels, identical except for deoxidation practice, which had been treated with ferroboron. The steel deoxidized with 2 lb. aluminum per ton before the boron treatment showed a marked superiority in hardenability over that of two other steels which were deoxidized with recommended amounts of titanium [1.2 lb. per ton titanium as low-carbon ferrotitanium in one instance, and as high-carbon ferrotitanium].

Practically the only reason for adding boron to steel has been the remarkable increase in hardenability accompanying very small additions. Recently, however, the now famous Smythe Report on the development of the atomic bomb had disclosed the use of steel rods supposedly containing high percentages of boron to control neutron intensity in the nuclear fission piles. Probably these rods are fabricated by special techniques and are low in carbon content.

Effect of Boron on Hardenability

The major effect of boron in steel is to increase its hardenability. All other effects are incidental (with the exception, of course, of the use just mentioned to control neutron intensity). For this reason, boron steels show their superior properties only in the quenched and drawn condition.

In the S.A.E. Technical Board report, Buswell, Danse, and McGrath write that the average Jominy hardenability (J-50) of their treated ingots (0.45% carbon, 1.50% manganese steel) was of the same order as that of S.A.E. 4145 steel used for comparison purposes, while at a Jominy hardenability of J-42 the S.A.E. 4145 steel was somewhat higher in hardenability than the average of the treated ingots that were tested.*

Grossmann reported a maximum multiplying factor of about 1.5. A multiplying factor from the work of Crafts and Lamont is 1.75. Udy and Rosenthal gave an average maximum multiplying factor of 2.0. Corbett and Williams showed an average maximum multiplying factor of about 1.55.†

Corbett and Williams reported that 0.003% boron in steel has an effect of 0.87% silicon, 0.79% nickel, 0.27% chromium, 0.12% manganese or 0.23% molybdenum.

Udy and Rosenthal show that, from a hardenability standpoint, boron can substitute for all of the molybdenum in steels of the two following compositions: *(a)* 0.30% C, 0.80% Mn, 0.25% Si, 0.50% Ni, 0.50% Cr, 0.40% Mo and *(b)* 0.30% C, 1.60% Mn, 0.25% Si, 0.40% Mo. However, because of the necessity for having some molybdenum present to suppress temper brittleness, only half of it should be replaced with boron.

Caution should also be observed when substituting boron for any other element. Special properties conferred by the element replaced, such as corrosion resistance or magnetic properties, may not be provided by the boron, although the substitution is perfectly all right with respect to hardenability.

Comstock, of Titanium Alloy Mfg. Co., working with N.E. 9440 and S.A.E. 4640 steels, reports that enough Carbortam added to give 0.003 to 0.004% boron in these steels would successfully replace about 0.6% chromium, 1.2% nickel, or 0.25% molybdenum. He cautions that the omission of molybdenum necessitates slightly lower tempering temperatures for equal properties.

Grange and Garvey published a curve showing the multiplying factor for four boron-treated steels plotted against carbon content. The multiplying factor decreased rapidly with increasing carbon content in almost a straightline relationship. Tisdale, of Molybdenum Corp. of America, said that his laboratory had also noted that steels of lower carbon content were more responsive to boron treatment. Schenck, of Buick Motor Division, General Motors Corp., also remarked that users of carburized "needled" steels had reported that hardenability of the case was not at all proportionate to that of the core.

This effect of carbon content on the response of steels to boron treatment can be used to explain some of the discrepancies among the multiplying factors reported by the various investigators. Udy and Rosenthal replotted the curve of Grange and Garvey and placed upon it their own value of multiplying factor for 0.30% C steels and the values recommended by Grossmann and by Crafts and Lamont. This is shown in Fig. 3, and agreement is very good. Udy and Rosenthal also note that their steels tend to be somewhat more responsive to boron treatment with increasing molybdenum content up to 0.40%.

Digges and his coworkers have shown that the boron effect in their steels was enhanced with

*Some readers may wish an interpretation of this short-hand notation: On the average, the depth of hardening to a C-50 level of steel from boron-treated ingots is about the same as for untreated 4145, but the depth to C-42 is somewhat greater in S.A.E. 4145.

†"Multiplying factor" is a term first used by Grossmann to express numerically the effect on hardenability of a stated amount of an element in steel. It is based on the concept that pure iron-carbon alloy has a certain hardenability and that each additional element is represented by a multiplying factor by which the base hardenability is multiplied. The value of the factor changes with the percentage of the element contained. For example, Grossmann obtained a multiplying factor for boron in a 0.63% carbon steel which ranged from 1.00 with no boron to approximately 1.50 with 0.0025% boron. With greater percentages of boron the factor decreased.

increasing amounts of manganese, chromium, and molybdenum. Nickel contents up to 0.6% did not have a similar influence.

Role of Nitrogen

Nitrogen has often been mentioned in connection with the effect of boron on hardenability. Some investigators believe the boron microconstituent to be a nitride. Chandler and Bredig, of Vanadium Corp. of America, in their discussion of the paper by Grange and Garvey, suggest that the hardenability effect of boron is neither an alloying

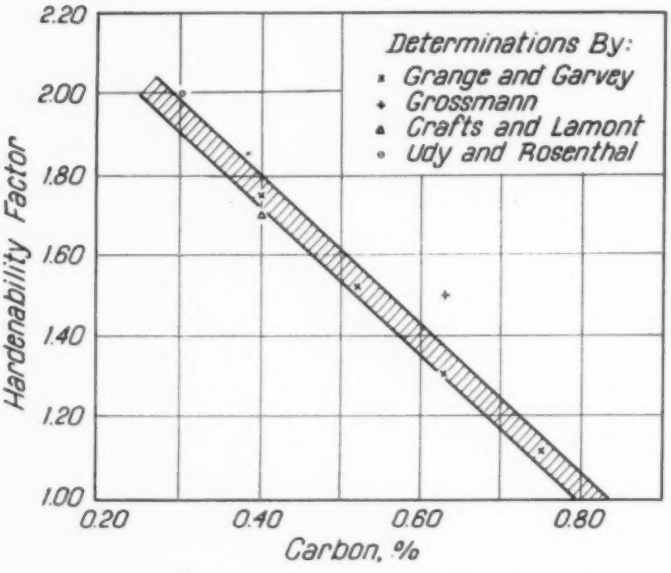


Fig. 3 — Relationship of Hardenability Factor for Optimum Amount of Boron to Carbon Content of the Steel

effect in the usual sense of the word, nor a compound formation with nitrogen, but appears to be the influence of a fluxing agent upon the particle size of nitrides of other elements like silicon, aluminum, titanium, and zirconium.

As regards the supposed interaction between boron and nitrogen, Digges reported that the hardenability of steels *without boron* is not appreciably affected by increase in nitrogen. High nitrogen, however, was detrimental to boron additions, but its deleterious effects on boron-treated steel could be somewhat counteracted by the addition of a small amount of titanium or zirconium. To quote: "Apparently the role of titanium or zirconium in enhancing the hardenability of boron-treated steels containing high nitrogen is to act as a 'fixer' for nitrogen by forming nitrides insoluble at hardening temperatures and thus decreasing the amount of soluble nitrogen for reaction with the boron."

In some work at Battelle, as yet unpublished, Manning and Udy found indications that, for some steels, treatment with boron was accompanied by a decrease in total nitrogen content. This was particularly true for some of the larger boron additions (0.006%). The effect did not occur every time and thus could not be reproduced at will. Further work on the subject was postponed.

Recovery of Boron From Scrap

In discussing the recovery of boron from scrap, Archer in 1942 summarized the situation by stating that about half of it is recovered on melting in a cupola, and that melting steel scrap in an open-hearth heat of less than 0.50% carbon would involve no problem in boron pickup.

Digges found that for two induction furnace heats in which 0.006% boron was added as ferroboron and Grainal No. 79, respectively, remelting under normal conditions recovered approximately 60% of the boron, while remelting under oxidizing conditions (1% millscale) showed a recovery of 25 and 50% (for the ferroboron and Grainal No. 79 additions, respectively). Because of variations in the content of the other elements, however, it was impossible to establish whether this recovered boron was in a form that was suitable to improve hardenability.

Effect on Isothermal Transformation

It is generally agreed that the effect of boron is to suppress the nucleation of ferrite and pearlite. This suppression is manifest in the isothermal transformation diagram by a shift to the right of the starting-of-transformation curves. There is no lowering of the curves, however.

This shift is shown in a diagram in the "Atlas of Isothermal Transformation Diagrams" published by United States Steel Corp., reproduced as Fig. 4. A similar shift is reported for the 0.45% carbon, 1.50% manganese steel described in the report compiled by Buswell, Danse, and McGrath. Boron therefore increases the incubation period but does not drop the temperature at which pearlite and ferrite form — a fact of importance because the ordinary elements added to increase hardenability shift the start-of-transformation curves both to longer times and to lower temperatures. For this reason boron has no power to produce the finer pearlite and the higher yield strength in a normalized steel that come from the addition of the other elements.

Likewise boron has no effect on the temperature range for martensite transformation, a fact that has been noted by many investigators.

including Digges and his coworkers. Udy and Barnett also found that boron had no effect on quench-cracking susceptibility, and these two facts led them to state that quench cracking is not increased by increased hardenability of itself, but rather by the simultaneous lowering of the temperature at which martensite transformation begins —an effect of other elements ordinarily added to steel to increase its hardenability. Thus, one good use of boron could be to increase the hardenability of a steel without simultaneously increasing its tendency to quench crack.

Effect on Physical Properties

Comstock, dealing with N.E. 9440 and S.A.E. 4640 steels with boron added as Carbortam substituting for portions of the chromium, nickel, or molybdenum, reported that tensile properties of oil quenched specimens, with or without boron, tempered to the same hardness were practically equal. Notched-bar impact was as good, or slightly better, for the steels with boron.

Udy and Rosenthal found no significant difference in notched-bar strength between the treated and untreated steels studied by them (0.30% carbon, nickel-chromium-molybdenum and 0.30% carbon, manganese-molybdenum steels with boron substituted for various amounts of the molybdenum) and tested at temperatures from room down to −80° F. No direct effect of boron was noted on temper brittleness although, as noted previously, replacement of too much of the molybdenum produced temper brittleness.

Buswell, Danse, and McGrath reported that (for their 0.45% carbon, 1.50% manganese steel) the values for yield strength, ultimate strength, and hardness were not materially affected by additions of boron in the form of any of the intensifiers used, when the specimens were tempered alike at 450, 600, 800, 1000, and 1200° F. When tempered at 450 or 600° F. the treated ingots showed superior P-values (combinations of ultimate strength and reduction of area) over those of the untreated ingot, but not at higher tempering temperatures. For steels tempered above 800° F. the notched-bar impact figures were not raised by boron; in some steels the addition was detrimental. Those same steels tempered from 400 to 600° F. showed some improvement in notched-bar toughness with the boron additions.

It has been noted by several investigators that boron substituted for other alloys, particularly for molybdenum, lowers the resistance to tempering. In other words, lower tempering temperatures, for the same hardness, are necessary for steels in which molybdenum and possibly chromium have been replaced by boron. The work of Digges brings out the fact that the notch toughness and the tensile properties of high boron (0.006%) steels may be inferior to those of similar steels without boron or with low boron. Sometimes the notch toughness for steels with small boron additions, fully hardened and tempered to high hardnesses, showed an improvement over the similar boron-free steels under the same conditions. For the steels tempered to low hardnesses, no effect could be noted.

Apparently, the major effect of boron on tensile properties is a result of its effect on harden-

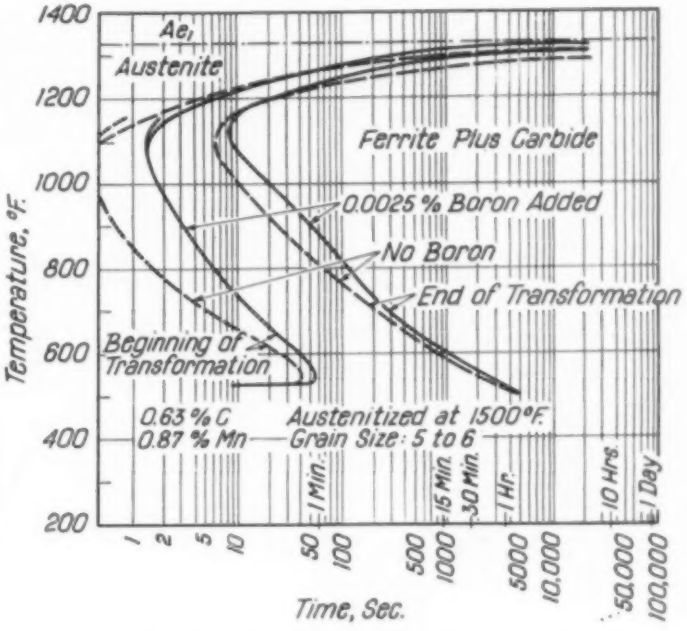


Fig. 4—Effect of 0.0025% Boron on Isothermal Transformation Curves of 0.63% C, 0.87% Mn Steel. (U. S. Steel Corp.)

ability. However, a large addition of boron, short of that necessary to produce hot shortness, may impair ductility and notch toughness.

Effect of Boron on Machinability

Claims have been made that boron increases the machinability of normalized steels. However, this improvement has not been found by all investigators.

T. G. Harvey, of Monarch Steel Co., reported tests on the influence of boron in a medium-carbon, resulphurized, openhearth steel. It increased in hardenability 31% and lost 5% machinability or more. (This 5% is probably within the limits of accuracy of the test.)

Buswell, Danse, and McGrath reported that

their treated ingots were practically the equivalent in machinability of the S.A.E. 4145 steel they were hoping to replace. They list the grinding characteristics of their ingots in the following order of decreasing ease of grinding:

1. Ingot treated with ferroboron
2. Ingot treated with Grainal No. 1
3. Ingot treated with Silvaz No. 3
4. Ingot treated with Grainal No. 79
5. Ingot treated with Borosil
6. Untreated ingot
7. Ingot treated with Silcaz No. 3
8. Ingot treated with Bortam

Udy and Rosenthal in some sawing and drilling tests on nickel-chromium-molybdenum and manganese-molybdenum steels found no significant differences between the boron-treated steels and the untreated steels in the quenched and tempered condition.

Comstock also reported no significant differences in machinability caused by boron in similarly heat treated steels other than those expected from differences in hardness. His steels were N.E. 9440 and S.A.E. 4640 with various percentages of the nickel, chromium, and molybdenum substituted by boron added as Carbortam.

Effect of Boron on Weldability

Digges made a limited number of tests on weldability and, for the conditions investigated, found that boron had no effect on the weldability of 0.30 to 0.45% carbon, 0.80 to 1.60% manganese steels.

Summary

1. Chemical, spectrographic, and microscopic techniques have been developed to such a state that extremely small amounts of boron in steel can be measured accurately.

2. Despite the accurate methods of measurement, it is still impossible to correlate the amounts of boron present in steel with its effect on hardenability.

3. High-temperature, long-time treatments may cause the disappearance of the boron microconstituent and at the same time convert the boron, effective for increasing hardenability, to an ineffective form. Such a conversion will probably be a rarity in commercial handling of boron-treated steels.

4. Of the numerous possible agents by which unoxidized boron may be added to steel, all appear to be equally effective if good steelmaking practice is followed. Some of the complicated alloys may be of advantage to reduce the grain coarsening tendencies of a boron addition. Because of lack of control of boron recovery, boron-containing oxides and borates have not as yet proved satisfactory agents.

5. Boron additions are not a substitute for good steelmaking practice.

6. For optimum results, the boron additions should be made to fully killed steel. Indications are that an optimum effect may be had when the size of the addition introduces from 0.001 to 0.002% boron into the steel. This is much below the percentages reported to produce hot shortness (0.006 to 0.007%).

7. The multiplying factor for this optimum amount of boron (in the Grossmann system for calculating hardenability) varies with the carbon content of steel, being about 2.0 at 0.30% carbon and decreasing to practically 1.0 for the eutectic composition. The multiplying factor may also depend upon the amount of other elements in the steel, increasing with the increase in amount of the other elements producing hardenability. High nitrogen is detrimental to the effectiveness of boron in this respect; this may be overcome, to some extent, by additions of titanium or zirconium.

8. Boron shifts the nose of the isothermal transformation diagram to the right but not downward, and does not affect the temperature range of martensite transformation.

9. Boron has no noticeable effect on susceptibility to quench cracks.

10. The major effects of boron are only found in fully quenched and tempered structures.

11. Boron has little effect on tensile properties other than through its effect on hardenability.

12. Boron has little effect on notched-bar toughness, although some improvement has been reported on material that has been tempered to high hardness values.

13. Boron has no noticeable effect on temper brittleness.

14. Care should be used in substituting boron for other elements, in that it may not supply the desirable characteristics produced by the element replaced. For example, substitution of boron for molybdenum will decrease the resistance to tempering and will not furnish the resistance to temper brittleness offered by molybdenum.

15. Boron appears to have little effect on machinability.

16. For the recommended size of addition, boron has no noticeable effect on weldability. (There are a quite limited number of tests substantiating this conclusion.)

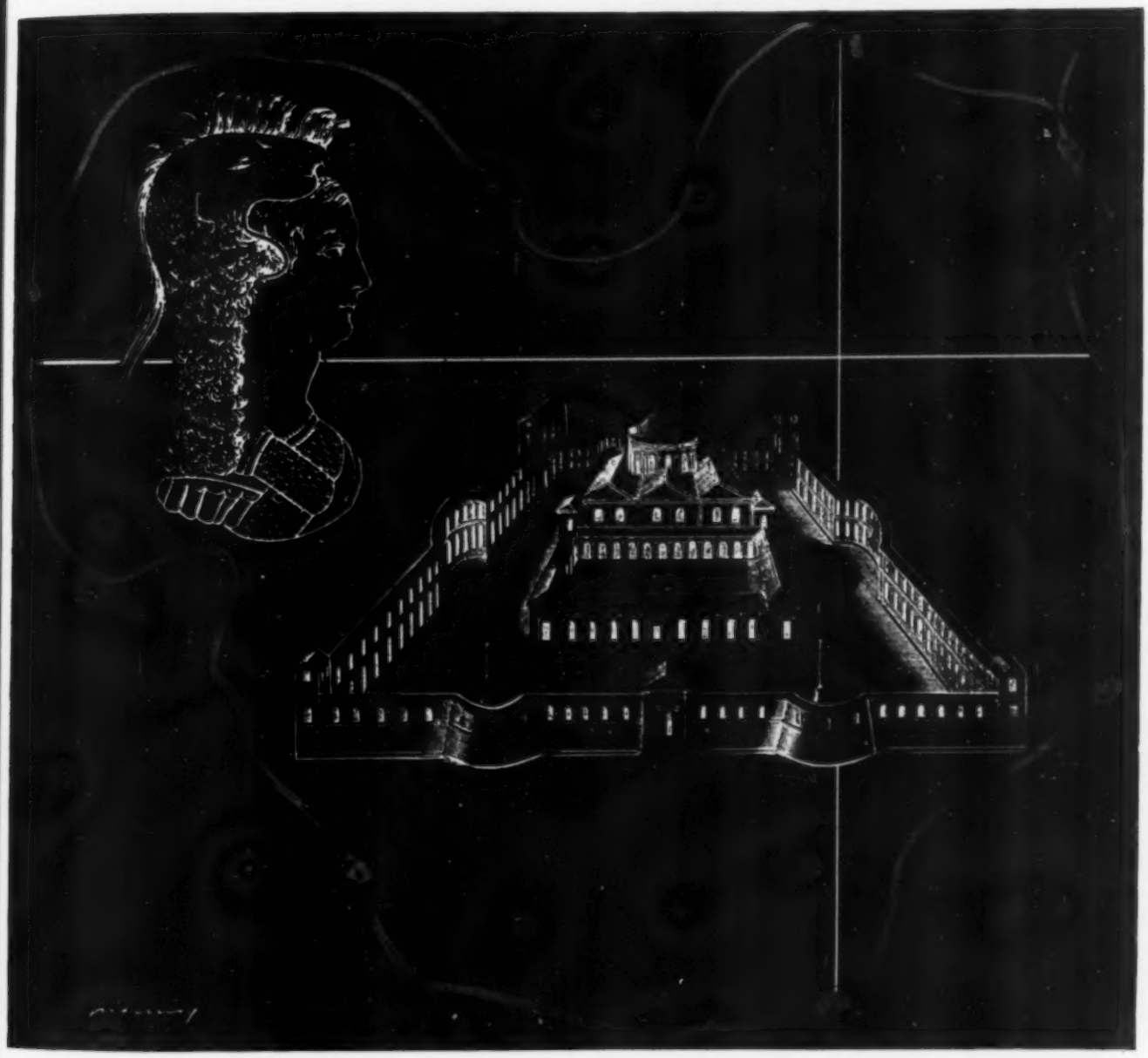
17. The whole story of the boron effect is not available but gradually the puzzle is being fitted together.

A LITTLE DOES A LOT

According to legend, when the city of Carthage was founded, Queen Dido was told that she could have only as much land as could be encompassed by an ox hide. But the queen made the most of her material by cutting it into a single, continuous leathern string, with which she circled considerable acreage.

Making materials serve to the fullest is just as important to users of steel today as it was to Dido. Except that today no tricks are necessary.

It can be done in many instances by specifying molybdenum steels. Their hardenability, freedom from temper brittleness and good strength-weight ratio help to simplify design problems and insure good performance. It will pay you to investigate their practical advantages.



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MOLY

Personals

Leaving Southern Liquid Gas Co., **W. L. Bruckart** has accepted a position as research engineer in the corrosion division of Battelle Memorial Institute, Columbus, Ohio.

Milosh Popovich has rejoined the staff of Oregon State College as assistant professor of mechanical engineering, having left his position in the process engineering department, Union Oil Co. of California.

H. M. George, formerly assistant chemist for the Colorado Fuel and Iron Corp., Pueblo, Colo., has been made chief chemist.

A. F. Ruffner, **B. O. Platell**, **G. M. Cook**, **L. E. Hamlin** and **Vincent Kennedy** have formed a new company, Metal Working Lubricants, Inc., Cleveland, to manufacture and sell industrial lubricants and heat treating supplies.

Capt. P. W. Snyder has been transferred from the Naval War College, Newport, R. I., to the Philadelphia Naval Shipyard.

H. G. Cornejo-Lopez has received a promotion from major to lieutenant colonel in the artillery branch of the Peruvian Army.

For the next year, **Floyd F. Dore** will be with the Brazilian Railway Equipment Co. of Sao Paulo, Brazil, where he will establish their electric steel melting practice and handle other related metallurgical details. He has been loaned to this company by his present employers, the American Steel Foundries.

Walter A. Fett and **M. E. Pillman** have organized the Cerecast Manufacturing Co., St. Louis, Mo., fabricators of jewelry and precision castings for industry.

James E. Atherton, Jr., is now with the Brookhaven National Laboratories, Long Island, N. Y.

L. V. Quartararo, who has been with the Los Alamos Laboratories as a junior scientist, is now chemist and manager of the Acqua Lina Manufacturing Co., Brooklyn, N. Y.

C. A. Nicklas, formerly representative in the aluminum division of Reynolds Metals Co., is now representative in the marine division.

Michael F. Wiedl, Jr., secretary of the Georgia Chapter, American Society for Metals, and previously associated with the Ernest H. Abernethy Publishing Co., Inc., is now managing and directing southern industrial shows and expositions.

Henry J. Becker is now associated with Holmes & Narver, military construction engineers, supervising mechanical installations on the island of Okinawa.

Paul Pelletier has recently been elected president of Chemco Products Co., Inc., Chicago, makers of industrial chemicals for metal-working trade.

C. W. Bentley is now metallurgical process engineer for Douglas Aircraft at the El Segundo, Calif., plant.

Resigning his position as staff metallurgist with the Beech Aircraft Corp., Wichita, Kan., **Howard A. Smith** is now research chemist with the Fansteel Metallurgical Corp., North Chicago, Ill.

Michael Powsner, formerly chemist in charge of the research and development laboratories of Jeffersonville Quartermaster Depot, is now laboratory management engineer for the research and development branch, military planning division, Office of the Quartermaster General.

BUT . . .

Though it was the pride of the early pioneers, in their push westward, it would be entirely inadequate for present day high-speed, heavy load, transportation needs. Today's huge modern, transcontinental trailer-trucks, testify to the triumph of American progress.

CHEMICALS ACP PROCESSES

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Duridine* is just as remarkable an improvement, in the metal-cleaning field. It cleans—removes oil and grease—and other surface soil—phosphatizes and changes the metallic surface into a non-conductive phosphate film, of uniform crystalline structure—provides a durable bond for organic finishes.

DURIDINE provides extraordinary protection for painted metal surfaces. It is applied by means of mild steel power-spray washers—and is a thorough, speedy and simple process.

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AMBLER ACP PENNA.

REVERE COPPER for TANKS

PROBABLY the first important industrial application of Revere copper sheet was in the boiler of one of Robert Fulton's steamboats. For tanks, boilers, water heaters, evaporators, fractionating columns, stills and other equipment copper is still the preferred metal.

High heat conductivity is an outstanding virtue. This means less fuel is consumed, and less time required, to bring liquid contained in copper up to the desired temperature.

Corrosion resistance is another vital factor. Copper resists the action of water and many other fluids indefinitely, protecting against contamination, and assuring long life for the boiler or tank.

Easy fabrication is equally important and means lower costs. Any of the usual fabrication methods may be used including welding. Revere will gladly cooperate with you on welding methods and procedures. And should it be necessary to replace a copper vessel for any reason, the metal has a high reclaim value.

Revere copper and copper alloys are produced in sheet and plate, roll and strip, rod and bar (including welding rod), tube and pipe, extruded shapes and forgings.

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Personals

Bernard S. Lement, previously teacher of physics at the University of Massachusetts, is now at Massachusetts Institute of Technology doing graduate work.

Having received his degree from Iowa State College, **Robert R. Austin** is now employed as mechanical engineer by the Dexter Co. of Fairfield, Iowa.

John L. Griffith, who has been associated with American Smelting and Refining Co. for 17 years, has been appointed sales manager for the New England territory for Federated Metals Division.

On the merger of the Budd Wheel Co., The Edward G. Budd Manufacturing Co. and the Budd Induction Heating Co. into The Budd Co., **C. L. Eksergian**, former chief engineer of the Budd Wheel Co., has been made executive engineer and assistant to the vice-president in charge of engineering in the new organization.

W. L. Pinner, manager of research and development of Houdaille-Hershey Corp., has been selected to direct the activities of the newly established research laboratory of the company.

V. H. Hiermeier has been appointed by Minneapolis-Honeywell Regulator Co. and the Brown Instrument Co. to establish a subsidiary in Mexico City to be known as Honeywell-Brown, S.A.

E. C. Smith, chief metallurgist of Republic Steel Corp. and recipient of the A.S.M. Gold Medal for 1946, was awarded a degree of doctor of science by Case Institute of Technology, Cleveland.

Thomas E. Cushing, formerly engineer with SKF Industries, is now chief engineer, Equitable Bearing Co., Walden, N. Y.

Having joined the Pacific Steel Co. on his release from 3½ years service in the U. S. Navy, **Edward S. Taylor** has recently been transferred from assistant metallurgist of the firm to sales engineer.

Silas R. Kimberly has recently organized a company for production of precision alloy steel castings and has named it Kimberly Cast Products, Inc., Los Angeles, Calif.

On release from active service in the Ordnance Department, **George T. Spencer** has joined the Highland Park, Mich., plant of Chrysler Corp. as methods engineer.

J. L. Sinback, formerly with Henderson Foundry and Machine Co., Hampton, Ga., recently organized and now has in operation the McDonough Foundry and Machine Co., McDonough, Ga.

John E. Decker has been promoted by National Forge and Ordnance Co., Irvine, Pa., from the position of metallurgical coordinator to that of chief metallurgist.

Gorton M. Goodwin was recently appointed senior physicist in charge of the physical testing section of the process laboratory of the Briggs Manufacturing Co., Detroit.

Robert C. Wallace, formerly vice-president and director of Marmon-Herrington Co., Inc., Indianapolis, is now executive engineer of Diamond T Motor Car Co., Chicago.

C. H. Cummings has joined Unitcast Corp., Toledo, Ohio, as metallurgist. He was previously with the Naval Research Laboratory in the physical metallurgy division.

A PRECISE HARDNESS TEST

of Microscopic Particles

Tin Oxide Crystal, magnification 1000X.

WITH a Spencer Bierbaum Microcharacter you can measure accurately the hardness of small areas, particles, and microscopic constituents of metals.

The specimen, highly polished and lubricated, is moved by micrometer feed beneath an accurately ground diamond point. The point is cube shaped for durability and ease of duplication. Pressure is precisely controlled so that hardness can be determined under the microscope by measuring the width of the resulting cut.

The Microcharacter is recommended for use with Spencer Metallurgical Microscopes. For further information write Dept. V119.

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$100,000 Worth of Hand Tools saved from "RUST"

NEW PRODUCT DOES THE JOB AFTER PLANT CONDUCTS EXHAUSTIVE TESTS

Lubrication Engineer's Report

"Some time ago, we were called in by a prominent manufacturer.* Corrosion of all metal parts in his entire plant had gone out of control. The machine shop and hand tools, valued in excess of $100,000, were a sorry looking 'dusty-brown.' Everything they had used in the way of rust preventives heretofore failed to solve their difficulty.

"After studying their problem we recommended our General Purpose Anti-Corrode No. 100 and suggested that they give it exhaustive tests. Their chemist did so and we are happy to report that it solved their problem.

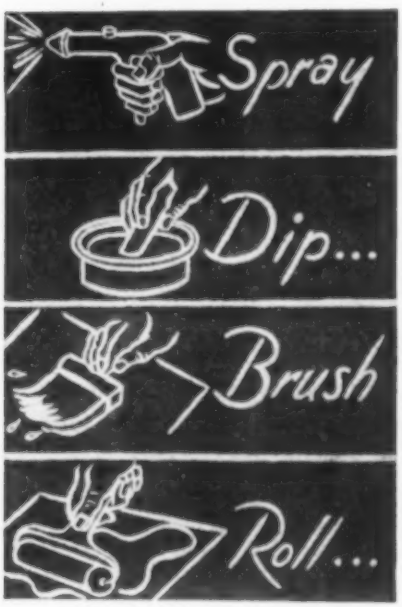
Used on Hand Tools As Well

"They have since used over 150 gallons of this Anti-Corrode on everything metal in their plant, including small hand tools such as pliers and screw drivers."

Anti-Corrode No. 100 is one of several new types of Cities Service protective coatings for metals. Designed to prevent corrosion of raw stocks, finished parts and completed machines, it adheres firmly, displaces moisture and protects longer than many materials now on the market.

Easy To Apply

Apply Anti-Corrode by ordinary work-shop methods. Spray, dip, brush or roll it on. The protective film is continuous and non-porous—does not break at sharp edges nor rupture on flat surfaces. It need not be removed from metal to be stamped, drawn or otherwise formed.



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Cities Service will demonstrate the many advantages of Anti-Corrode to you in your own plant. Contact the branch office nearest you or write Cities Service Oil Co., 60 Wall Tower, New York 5, N. Y.

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Gentlemen: I'd like to test ANTI-CORRODE No. 100 on my own equipment FREE OF CHARGE. Send me details.

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Personals

Tom Barlow, previously with the Vanadium Corp. of America and Battelle Memorial Institute, has joined the Eastern Clay Products, Inc., as general sales manager.

Donald B. Roach, former Naval officer, has joined the staff of Battelle Memorial Institute, Columbus, Ohio, where he will be engaged in research in welding technology.

After ten years with the Caterpillar Tractor Co., **Herbert L. Vernon** has resigned to accept the position of chief engineer of the R. J. Piper Manufacturing Co., Princeton, Ill.

Alan E. Flanigan is now assistant professor of engineering at the University of California's new engineering school at Los Angeles.

Lloyd W. Myers, formerly on the metallurgical engineering staff at Purdue University, has accepted a position in raw material development at Western Electric Co.'s Hawthorne works in Chicago.

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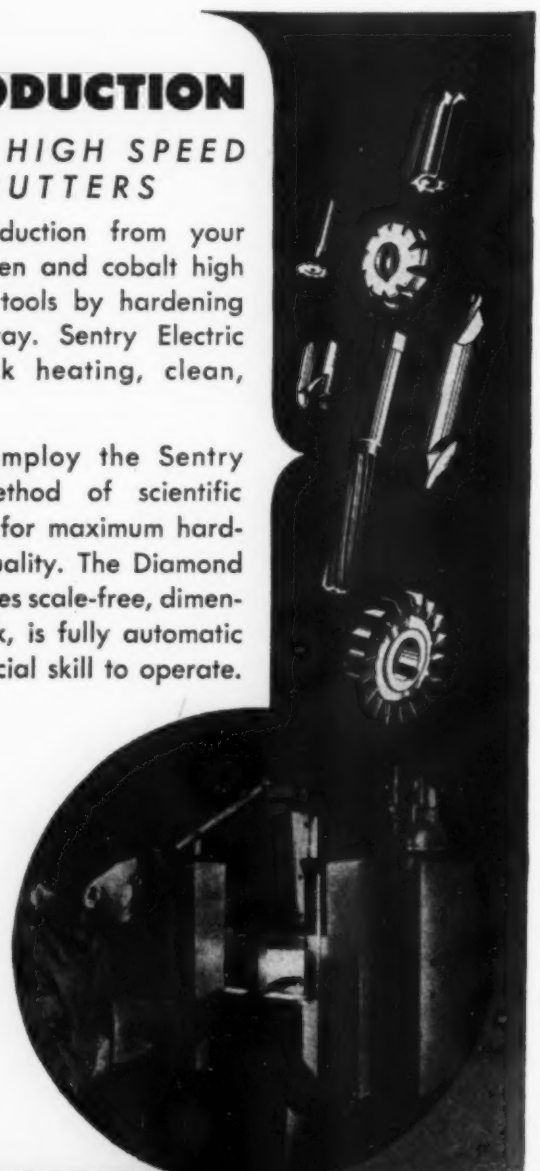

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Sentry DIAMOND Block

John A. Kriva is now product engineer in the hay machinery division of J. I. Case Co., Racine, Wis.

Formerly development metallurgist with Fansteel Metallurgical Corp., **Don H. Blackmar** has become chief metallurgist at Modine Manufacturing Co., Racine, Wis.

E. H. Farmer has been appointed plant engineer, Lockheed Aircraft Corp., Burbank, Calif.

Stephen Matovich, Jr., has joined Solvay Process Co. of Hopewell, Va., as assistant engineer.

Hartford works, Underwood Corp., has recently appointed **F. C. Shaffer** to the position of chief engineer.

Adrienne Scotchbrook is now assistant research engineer in the Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.

After completing his course of study at the Missouri School of Mines and Metallurgy, **S. P. Salarano** has accepted a position in the St. Louis office of Joseph T. Ryerson & Son, Inc.

Donald E. Hall has joined the mechanical engineering department of the University of Missouri on the completion of his undergraduate work at Iowa University.

Chester S. Pondo has recently been appointed by the Precision Tube Co. of Philadelphia to make metallurgical studies on nonferrous materials in their expanded laboratory.

Monroe Miller and **Joseph F. Kramer** have recently become coowners of the Richwood Plating Co., Richwood, Ohio.

Ohio Public Service Co. has transferred **Nathan J. Roberts** from industrial engineer of the Warren division to general industrial engineer with headquarters in Cleveland.

E. C. Wright has resigned as assistant to the president of National Tube Co. to become head of the department of metallurgical engineering of the University of Alabama at Tuscaloosa, Ala. He will engage in research and consulting work in addition to his teaching.

Earl O. Smith, formerly with the eastern procurement district of the Army Air Forces as assistant chief of materials and processes, has been transferred by Carnegie-Illinois Steel Corp. from the Ohio works to the Vandergrift plant of the Irvin works where he will also be development metallurgist.

THE BURRELL CO_2 INDICATOR

For a quick accurate check on your furnace efficiency

The *Burrell CO_2 Indicator* measures the CO_2 content of the stack gas in less than a minute and directly indicates the value on a long, clear, easily read scale. The Burrell Combustion Indicator, included with each instrument, quickly converts the CO_2 reading and the stack temperature into terms of combustion efficiency and heat loss and provides directions for bettering firing conditions.

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NO. 11 ALLOY
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The manufacturing of high electrical conductivity castings is no longer restricted to a highly specialized group of foundries.

It is now open to all foundries. There are no secret arts or formulae.

"Falls" NO. 11 ALLOY
—degasifies and deoxidizes the copper.
—protects the molten copper from reoxidation up to and during the pouring operation.

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Smelting & Refining Division
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Personals

R. H. Frank, superintendent of melting, Bonney Floyd Co., Columbus, Ohio, has been elected president of the Electric Metal Makers Guild, Inc., for the coming year; **A. J. Scheid, Jr.**, superintendent of melting, Columbia Tool Steel Co., Chicago Heights, Ill., has been elected vice-president; **D. L. Clark**, superintendent of melting, Simonds Saw and Steel Co., Lockport, N. Y., has been chosen secretary-treasurer.

E. E. Stansbury, assistant professor of metallurgical engineering at the University of Cincinnati, will join the staff of the department of chemical engineering of the University of Tennessee as associate professor in the fall.

J. B. Neiman, general manager of all the aluminum departments of Federated Metals Division of the American Smelting and Refining Co., Detroit, has been re-elected president of the Aluminum Research Institute.

William E. Karry, previously with a United States Steel subsidiary and the Karith Chemical Co., has been appointed director of methods and procedures at the Division Lead Co., Chicago.

The Presmet Corp., manufacturer of powder metal products, announces that **Melvin W. Isaacson** will be in charge of their Chicago offices.

A. B. Gibson, founder and president of the Gibson Electric Co., Pittsburgh, Pa., was awarded the honorary degree of doctor of engineering by the Clarkson College of Technology, Potsdam, N. Y.

Atlas Steels Limited, Welland, Canada, announces that **Edward P. Geary** has been elected vice-president and general sales manager. Mr. Geary is closing out Geary Stainless Steel Co., in Baltimore, Md.

Kloster Steel Corp., Chicago, announces that **James B. Cook**, who was previously serving as metallurgical engineer and manager of sales, has been appointed president and general manager.

Frank S. Brewster, formerly metallurgist at the Dowmetal Foundry, Dow Chemical Co., has joined the Harry W. Dietert Co., Detroit, Mich.

S. S. Pierce, of Birmingham, Mich., has joined General MacArthur's staff in Tokyo as industrial engineer.

Talk about fast metal melting at low cost!—the Type LF, 200 lb. DETROIT ROCKING ELECTRIC FURNACE illustrated above melted more than *two tons of red brass in one day's typical operation by one man.* In just 9 hours, this small and compact unit melted 27 heats of leaded bronze—200 lbs. per heat—for a total of 5400 lbs. *Power consumption, only 281 Kwh per ton.* Simple DETROIT ELECTRIC FURNACE design makes one-man operation easy. Non-rotating electrodes, supported by brackets mounted on the base, receive power from either overhead or below via copper conductors. Withdrawing electrodes frees shell for easy interchange to permit melting heats of various analyses. All controls are at operator's fingertips, assuring quick, positive regulation of melting time, composition, and other melting factors. Send us your ferrous and non-ferrous metal melting requirements. We will recommend the specific DETROIT ELECTRIC FURNACE—available in 10 lb. to 8000 lb. capacities—to speed quality metal production in your plant.

DETROIT ELECTRIC FURNACES

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AJAX
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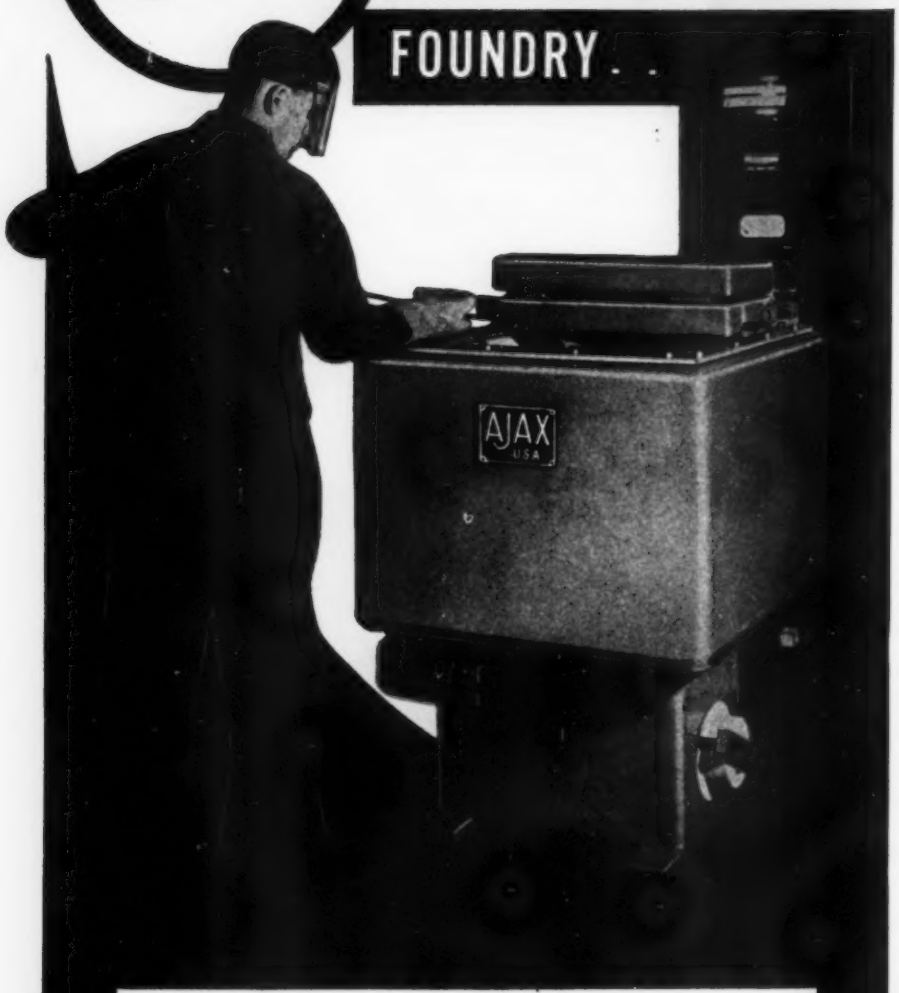
ELECTRIC FURNACES
for the ALUMINUM ALLOY
FOUNDRY . .



THE AJAX-Tama-Wyatt Low Frequency Induction Furnaces are now made in small sizes with capacities ranging from 20 to 35 kw.

Their operation is based on the induction principle whereby energy is transmitted to the molten charge without actual contact, through the refractory walls. Only the metal is heated, and therefore, there are no resistors or other parts having a higher temperature than is absolutely necessary for properly melting the charge. A gentle movement of the bath insures uniform temperature and homogeneous mixing of the alloy ingredients. Linings are made of inert refractories which do not contaminate the melt.

These melting machines are delivered with self-contained, completely factory wired control cubicles, including automatic temperature controllers.

AJAX ENGINEERING CORPORATION, Trenton 7, N. J.

AJAX TAMA WYATT INDUCTION MELTING FURNACE

AJAX METAL COMPANY
AJAX ELECTROTHERMIC CORP.
AJAX ELECTRIC CO., INC.
AJAX ELECTRIC FURNACE CORP.

Personals

Pol Duwez has been appointed associate professor of mechanical engineering at California Institute of Technology, Pasadena, Calif.

Ohio Ferro-Alloys Corp. announces that **James C. Vignos** will assume charge of sales in the home office at Canton, Ohio.

Amalgamated Steel Corp. announces that **H. E. Zecman** will head the new Malga Steel Service offices in Detroit.

Hugh J. Fraser, vice-president of The International Nickel Co., Inc., has been placed in charge of all plant operations of the company in the United States.

M. E. McKinney has been transferred by the International Harvester Co., Chicago, from supervisor of the metallurgical section of the ordnance research department to chief research chemist of manufacturing research.

Arthur W. Wood, formerly with the Westinghouse Electric Corp.'s Springfield works, has joined the Baker Ice Machine Co., Inc., as plant superintendent of the recently established South Windham plant in Maine.

Ellsworth T. Cander is now director of research and development with the Lea Manufacturing Co., Waterbury, Conn.

Louis J. Rohl, formerly assistant chief metallurgical engineer of Carnegie-Illinois Steel Corp., has been appointed chief metallurgical engineer to succeed **E. T. Barron**, who is retiring after 42 years with the corporation.

Sam Tour & Co., Inc., and its affiliate, the American Standards Testing Bureau, Inc., announce the appointment of **Leslie S. Fletcher** as technical director. Col. Fletcher is being retired from the Army after completing 23 years' commissioned service.

F. J. Reha has returned to the Udylite Corp. of Detroit following the recent sale of the Kiser Plating Co. at Muncie, Ind., in which he was a partner.

Walter J. Engel, formerly research engineer at Battelle Memorial Institute, is now research metallurgical engineer at the Aircraft Engine Research Lab., National Advisory Committee for Aeronautics, Cleveland.

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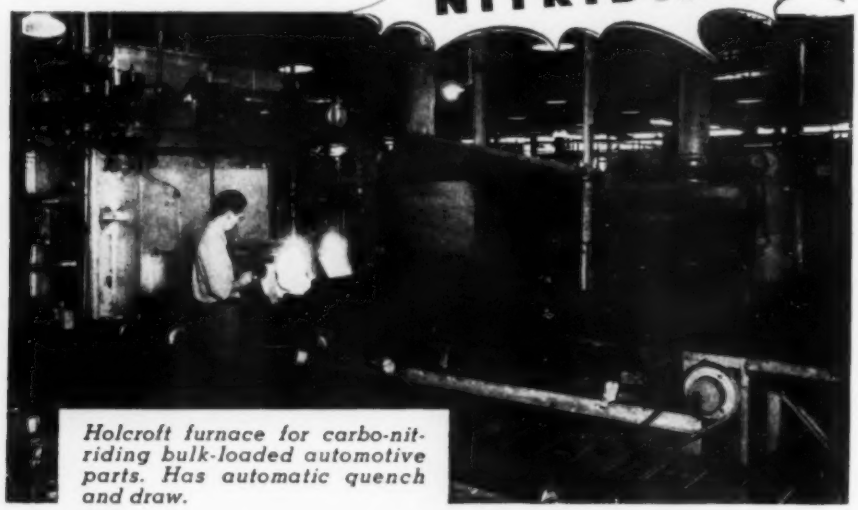
STOODY HARD-FACING ALLOYS

Retard Wear **Save Repair**

BLAZING THE HEAT TREAT TRAIL . . .

CARBO-NITRIDING



Holcroft furnace for carbo-nitriding bulk-loaded automotive parts. Has automatic quench and draw.

A SUPERIOR CASE-HARDENING PROCESS

Developed by *Holcroft*

CARBO-NITRIDING provides a "gas cyanided" case by heating the work in a controlled atmosphere composed of generator gas, hydrocarbon gas and ammonia. This Holcroft process uses continuous-type furnaces such as the unit shown above, and offers these advantages:

1. Low operating cost—often as low as one-fourth that of liquid cyaniding.
2. Superior wear resistance—greater than with carburizing.
3. Greater depth of hardenable case obtained per unit of time than by carburizing at the same temperature.
4. Minimum distortion through low-temperature operation and slow cooling when required.
5. Applicable to both plain carbon and alloy steels.

Although the theory behind carbo-nitriding is mentioned in a patent issued in 1883, it was not applied to high-production furnaces until rediscovered independently by Holcroft & Company in 1936. The first furnaces of this type, built 11 years ago, are still in operation; and many other production furnaces installed since then have further proven the merits of this process.

The Holcroft engineering leadership which developed carbo-nitriding is available to serve you—offering the advanced features and specialized design which assure better results at lower cost in heat treat work of every kind. We invite your inquiries.

PRODUCTION HEAT TREAT FURNACES FOR EVERY PURPOSE

SINCE 1916

HOLCROFT & COMPANY

6545 EPWORTH BOULEVARD
DETROIT 10 • MICHIGAN

Chicago 3: C. H. Martin
1017 Peoples Gas Bldg.

Houston 1: R. E. McArdle
5724 Navigation Blvd.

Canada: Walker Metal Products, Ltd., Walkerville, Ontario

Flame Shortening*

BRIDGE PINS and holes in eyebar-ends in many old pin-connected truss bridges have been subjected to a high rate of wear as a result of stressing under traffic of high speed heavy locomotives. In some spans, many of the eyebars have become so loosened through wear that they carry little if any of the total stress. When live-load strains in various eyebar tension members were measured, it was found that one bar of a two-bar member might carry as much as 97% of the total load until it elongated sufficiently to bring the pin in contact with the head of the loose eyebar.

Various methods have been used to tighten loose eyebars. Probably the most common involves cutting the member and welding or riveting a turnbuckle into it. This method is relatively expensive. Moreover, the fatigue strength in the arrangement tested, involving overlapped material joined by fillet welds, was only about 35% of the original eyebar.

Another method is to cut out a short section and then draw the two sections together so the ends come in contact with their pins. The two heads are then spliced by welding or riveting plates on both sides of the bar. Very little initial stress can be placed on the bar shortened in this manner, and the fatigue strength of the bar tested was only about 50% of the original.

The method which appears most practical is to heat a small section of the bar to about 1600 to 1800° F. and then to upset the heated part by screwing up two long bolts reaching between two special clamps straddling the heated region. Charcoal furnaces, used successfully for several years, have been replaced by oxy-acetylene torches which reduce the heating time and give a more uniform temperature distribution. This oxy-acetylene method ("flame shortening") takes less time and is more economical. Equipment is standard with bridge crews with the exception of clamps and a pyrometer. Flame shortening eliminates costly train delays as only one hour *(Cont. on p. 278)*

*Abstracted from "The Shortening of Eyebars to Equalize the Stress". Preliminary Report of Committee 15—Iron and Steel Structures. Reprint American Railway Engineering Association's Bulletin No. 460. *Welding Research Supplement*, December 1946, p. 849-s to 856-s.

DU PONT *announces–*

free washing

Accelerated Salt WS

New Du Pont development is ideal for producing intermediate cases.

Look at these features:

1 **FREE WASHING**—The salts composing this bath and their decomposition products are completely water soluble. Even detergents which may be used in cleaning oil-quenched work do not precipitate water insolubles with the Du Pont Accelerated Salt WS.

2 **EXCELLENT CARBURIZING ACTIVITY**—over a wide operating temperature range (1510-1650 F). See case depth chart at right. ⟶

3 **BAIL-OUT ELIMINATED**—The high cyanide content of the Accelerated Salt WS (66% NaCN, minimum) will maintain the average bath at operating strength by simply replenishing dragout losses.

4 **EXCELLENT FLUIDITY**—A minimum of salt dragged out on the treated work.

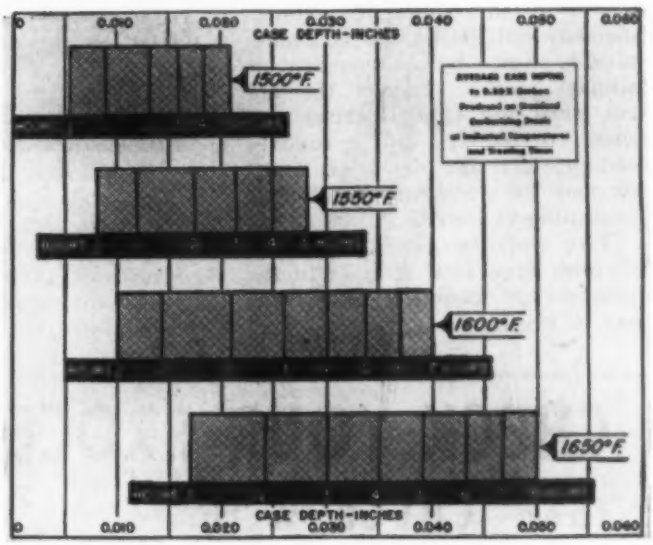
5 **LOW MOLTEN DENSITY**—Less salt for the initial charge and reduced fresh salt replenishments as compared to the barium-activated salt baths.

6 **MINIMUM HEAT RADIATION LOSSES AND FUMING**—with the floating graphite cover. For the convenience of the operator, graphite is incorporated into the Du Pont Accelerated Salt WS mixture.

7 **EASY TO HANDLE PELLETS**—uniformly sized weighing approximately one ounce. A minimum of dust to annoy the operators when making bath replenishment additions.

8 **NO SLUDGE FORMATION**—from infusible salt residues. All salts in the Du Pont Accelerated Salt WS mixture and their decomposition products form an homogeneous melt at operating temperature.

9 **SIMPLE BATH CONTROL**—A single replenishment will maintain activity for at least twenty-four hours at operating temperature. Cyanide analysis, which is rapid and simple, is the only chemical control required.



For further information on Du Pont Accelerated Salt WS, or for experienced advice and technical assistance in selection and application of any Du Pont heat-treating materials, write or call our nearest district office. E. I. du Pont de Nemours & Co. (Inc.), Electrochemicals Department, Wilmington 98, Delaware.

District Offices: Baltimore, Boston, Charlotte, Chicago, Cincinnati, Cleveland, Detroit, El Monte, Calif., New York, Philadelphia, Pittsburgh, San Francisco.

BETTER THINGS FOR BETTER LIVING...
THROUGH CHEMISTRY

DU PONT

DU PONT
CYANIDES AND SALTS
for Steel Treating

Flame Shortening

(Continued from page 276)

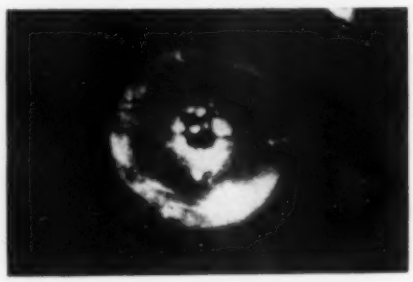
is required per bar. Tests showed that flame shortening had no appreciable effect on the steel's fatigue and static strength.

The technique is as follows: Remove paint for a distance of about 4½ ft. and bolt clamps to the eyebar, but do not put any tension in the shortening device. Place supports so bar will not sag when heated, and a canvas windbreak, if necessary. Place trammel points about 4 ft. apart, straddling the clamping device. Heat both sides of the eyebar for about 12 in. to a cherry red (contact pyrometer reading of 1600 to 1800° F.). Tighten nuts on all shortening bolts simultaneously until the required shortening is shown by measurement of trammel points. Protect the hot area until the temperature has fallen to 1000° F. by pyrometer reading; if traffic demands it the bar may be water quenched after air cooling to 1000° F.

The article gives methods whereby dead load stresses in the eyebars and required shortening may be computed.

Tracer Micrography

A NOTE from the Bureau of Standards tells of some work on the problem of recording a fine structure, one of whose elements has radioactive isotopes intentionally introduced. The old method of merely placing a photographic plate alongside lacks resolving power, since details less than 100 microns (0.1 mm.) cannot be distinguished. The new method utilizes what is in effect an electron



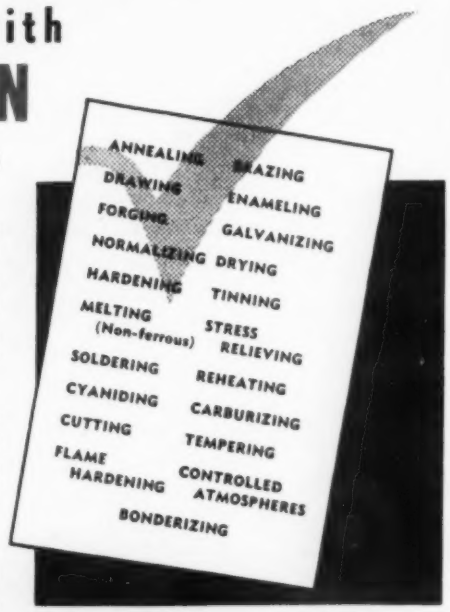
microscope, and therefore is limited to elements whose disintegration evolve beta rays (fast electrons) of uniform speed. The preliminary experiment was with gallium 67, separated from *(Cont. on p. 280)*

CHECK YOUR PROCESSES

then CHECK with

WARREN

For Liquefied Petroleum Gas



Industrial uses for LP-GAS are rapidly increasing in number and volume. Manufacturers are finding that LP-GAS is the most efficient fuel for tool hardening, cutting, normalizing, die casting and many other processes.

LP-GAS is your best and most dependable source of heat and Warren is your best and most dependable year 'round source of LP-GAS supply.

Contact your nearest Warren office today and take advantage of our experienced consultation service.

"1922 - Silver Anniversary Year - 1947"

WARREN PETROLEUM CORPORATION
TULSA, OKLAHOMA
Detroit Mobile Houston

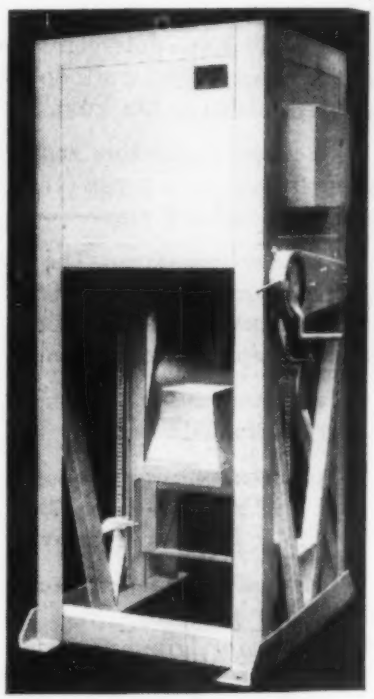
QUESTIONS AND ANSWERS ABOUT

Harper

ELECTRIC FURNACES

8. *Why are Harper Electric Furnaces Convenient to Use?*

All Harper Furnaces are designed for convenience and safety. Heavy insulated doors, elevating hearth mechanism, continuous conveyor belts, standard, inverted and tilting designs contribute to better operation, easy handling of crucibles and materials.



Harper Inverted Pit-Type Electric Furnaces are equipped with a counter-balanced hearth elevating mechanism—hand- or power-operated. Crucible can be lowered for easy handling with tongs . . . reduces spillage . . . saves valuable materials and fragile crucibles . . . simplifies inspection . . . eliminates direct radiation to operator.

Put your high temperature furnace requirements up to Harper.

Representatives in principal cities.

Harper
ELECTRIC FURNACE CORPORATION

1450 Buffalo Ave. Niagara Falls, N. Y.

Here's what you can do with this Blowpipe . . .

. . . and, by selecting from a choice of 57 different nozzles you can use the OXWELD C-32 to do almost any metal-cutting job practicable with manual equipment.

This sturdy cutting blowpipe is easy to handle and is built to give years of economical service even under the most strenuous conditions of use. A specially designed mixing chamber provides high flashback resistance. The C-32 operates on medium-pressure (5-15 lb. per sq. in.) acetylene.

Write for a catalog or ask Linde to demonstrate the advantages of this blowpipe.

The word "Oxweld" is a registered trade-mark of Union Carbide and Carbon Corporation.

THE LINDE AIR PRODUCTS COMPANY

Unit of Union Carbide and Carbon Corporation

30 E. 42nd St., New York 17, N. Y. UCC Offices in Other Principal Cities

In Canada: Dominion Oxygen Company, Limited, Toronto

O-ALLOYS THE QUALITY NAMES IN ALLOY

"Zincilate*"

Cuts Corrosion Costs!

"Beats the Devil Out of Corrosion"

20 YEARS LIFE

Estimated Usage, Based on 1000 Hours ASTM Salt Spray Treatment

● ZINCILATE, THE ONE-COAT SELF-PROTECTING ANTI-CORROSIVE COATING, can be applied on ferrous metals and aluminum . . . sheet, strip, wire, forgings and castings. ZINCILATE can be sprayed, dipped or brushed. No special equipment is required. It can be baked either in convection or infrared oven or by hot air blast, or by open oxyacetylene flame. Accelerated tests to A.S.T.M. specifications show no corrosion of ZINCILATE after one thousand hours' exposure to salt corrosion treatments.

ZINCILATE IS NOT A COMMON, TYPICAL ZINC BASE PAINT

ZINCILATE is a revolutionary inorganic coating containing no resins, oils or solvents. It is based on chemical and physical principles never before employed in anti-corrosive coating materials. ZINCILATE is applied to a thickness of only two or three mils. Protection with ZINCILATE does not depend on the self-sacrificial action of zinc, therefore, does not depend on a heavy coating. ZINCILATE weighs one ounce per square foot at two mils thickness and covers four hundred square feet per gallon.

Zincilate is a low cost coating. It is a one-coat application, saving labor and material. It requires no primer. It has great covering power due to its uniform thickness in a coating film of two to three mils. It lasts many times as long as ordinary protective coatings, eliminating replacement and repair.

USES for "ZINCILATE"

Iron and Steel Manufacture

Shipbuilding

Railroads

Construction

Utilities

Manufactured Products

Characteristics and Technical Data: Color: gray. Finish: dull matte or bright polished. Viscosity: 20 seconds ± 4, #4 Ford cup initial; after five days, 35 seconds. Weight, gallon, 26.70 ± .5. Hardness: Rockwell at 5P measures 40B. Abrasion: excellent — 68,000 cycles Taber F10-1000 gm. load. Adhesion: excellent. Coverage: 400 square feet per gallon (approx.). Corrosion Resistance: salt spray treatment for 1,000 hours, no failure (estimated equivalent, 20 years in use). Weatherometer—3,600 hours, no failure. Film Properties: withstands air temperatures to 700°F, transient heat to 6300°F.

*Trade Mark

INDUSTRIAL METAL PROTECTIVES, INC.

137 NORTH PERRY ST. **DAYTON 2, OHIO**

***PRICES:** $8.00 per gallon in drums • $10.00 per gallon in one-gallon cans • $9.50 in 5-gal. cans • Tank Car lots of 10,000 gal. $7.20 per gal. F.O.B. Newport News, Va.*

BUY "ZINCILATE" FOR YOUR anti-corrosion applications, *today!*

Use this convenient order form . . . we'll bill you upon shipment.

Ship _____ **gallons "Zincilate" @** _____ **per gallon to:**

Company _____

Address _____

City _____ **Zone** _____ **State** _____

Signed: _____ **Title** _____

Tracer Micrography

(From p. 278) zinc chemically as the chloride, bombarded in a cyclotron, and the solution evaporated drop by drop on a small tantalum disk. Radiation from the surface of this disk, upon passing through a magnetic lens consisting of a small iron-clad coil with Armco iron pole pieces, was brought to a focus on a photographic film at a distance of about 3½ in. An image of the tantalum disk was thus obtained showing radioactive areas; the magnification was about twice natural size. The best resolving power attained so far has been about 30 microns (0.03 mm.).

The method is simple, both in apparatus and technique. Vacuum requirements are very moderate. It is expected that after-acceleration of the beta rays by a homogeneous electrostatic field will cut the exposure time and give considerably better resolution.

Abnormal Creep*

DETERIORATION in creep characteristics caused by differences in the amounts of aluminum and silicon added as deoxidizers is called "abnormal creep" by the author. The existence of abnormal creep, however, depends not only on deoxidation practice but also on the testing temperature and the thermal history of the sample. The phenomenon appears to be related (perhaps indirectly) to the McQuaid-Ehn grain size, abnormal creep being accompanied by fine grain. The problem of abnormal creep has an important bearing on the economics of production, particularly of billets for rotary piercing, since prohibition of aluminum deoxidation would bring many difficulties to steel manufacturers.

Five-day creep tests at 840°F. with a stress of 17,920 psi. were carried out on a series of low-carbon steels with 0.4 to 1.5% manganese, 0.01 to 0.15% silicon, 0 to 0.11% molybdenum and varying amounts of aluminum up to 3 lb. per ton. Most of the steels were melted in an 18-lb. induction furnace, but some tests were made on basic openhearth steel. The McQuaid-Ehn grain size became finer with increasing aluminum additions. Test bars were *(Cont. on p. 282)*

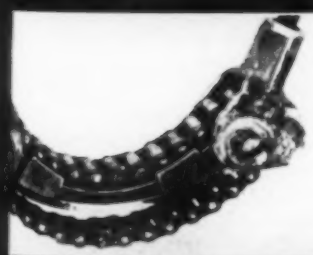
*Abstracted from "Abnormal Creep in Carbon Steels" by J. Glen, *Journal* of the Iron and Steel Institute, V. 155, April 1947, p. 501 to 512.

GA ALLOYS THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION X-ite

"Wild Irishman" Sends Platypus From "Down Under"

OM BREENE promised to Air Express two Honey s to GA for the Atlantic City A.S.M. Show. Regula- s interfered, but that didn't stop Tom Breene! So mmy's pal, David H. Fleay, landed in New York from lesville, Victoria, Australia, with Penelope, Patricia, Peter Platypus. They are now housed in the New York logical Garden where it is hoped they will make Platypi. s picture of Penelope, her signature witnessed by David ay and Tom Breene, will hang in our new "Dukyot" latypus" now nearing completion.

ENERAL MOTORS—Holdens, Ltd. of Melbourne are alling three heat treats under Tommy's supervision. He the heat-treat at Chevrolet Gear and Axle before the sold, built and installed furnaces for Salem Engineering England and Europe, returning to run Allison Engineer- 's Air Engine Heat Treat. Tommy *earned* his unusual gnment to pilot our Aussie friends into automotive allurgy.



General Alloys Engineered Castings *Should* Cost More

WE ARE not a "foundry", producing castings by the pound, but essentially an engineering organization selling heat treat tooling and high temperature equipment **on the basis of lowest cost per heat hour and ultimate service rendered.** There are many with less experience, inferior engineering, and "economies" of manufacture who sell alloy castings 20% below GA prices. This is probably the lowest spread between top quality and mediocrity in any industry. Nowhere is **Top Quality** more essential or more economical than in **high temperature operation.**

BAMBI LIKES the ladies. His social orbit is widening. Lucinda Franks, infant daughter of Tom Franks (Manager GA Chicago office), rough-housed him and made him like it. He attended a technical session at National Advisory Committee for Aeronautics and got his picture, shown here, in their house organ, "Wing Tips".

BRENDA, OUR lady Dane, is recovering from her second eye operation but is still blind. Bambi is in training as her "Seeing-Eye".

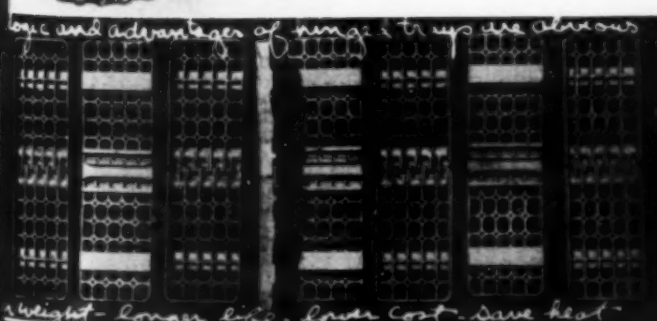
THE WELL engineered modern pump-housing shown makes full use of advanced alloy metallurgy by applying uniform sections, avoiding heavy flanges and the "gobs" of metal unfortunately present on most stainless castings made from traditional brass, steel or iron designs.

THE HOT roller bearings run on a flexible race at temperatures to 2,000 degrees F. They emphasize the advantage, if not the necessity, of **modern engineering** to keep pace with **metallurgical progress.**

"HINGE-TRAYS" having demonstrated their overwhelming superiority in three-rail pusher furnaces generally reducing costs from 50% to 80% over solid trays are the most copied design in alloy.

MANY THANKS to Major Carpenter, "Near-Editor" of the **unequalled** Houghton Line, for his nice story on our "Dukyots". Houghton products make them practical for civilian use.

ASM Detroit Chapter had the best outing yet. We got a good color shot of that fan dancer as the feathers tickled Bambi's nose.



GENERAL ALLOYS CO.
BOSTON U.S.A.

GENERAL ALLOYS will make pro-rata cash rebate cost-per-heat-hour guarantees on our "Hinge-Trays" and "Hot-Buggy" trays against any competitive tray employing any "hinge" or "articulated" variation thereof or against any solid tray in a three-rail furnace.

THE FOOTSTEPS OF GENERAL ALLOYS MARK THE PATH OF AN INDUSTRY

JOHNSTON
SLOT TYPE FORGING
FURNACES

Furnace with 2 slots as shown—for forging various shapes. Also single slot in light and heavy duty types.

Write for Bulletin M-233

Equipped with JOHNSTON Reverse Blast Low Pressure Burners—for Oil or Gas. They diffuse the finely atomized oil or gas through the air supply to produce complete combustion and maintain proper furnace atmosphere necessary for quick clean heating and to avoid scaling and surface decarburization. Low operating cost.

THE JOHNSTON LINE — JOHNSTON MANUFACTURING CO. 2825 EAST HENNEPIN AVE. MINNEAPOLIS 13, MINN.

ENGINEERS & MANUFACTURERS OF INDUSTRIAL HEATING EQUIPMENT

The Mail*... that did not come through

* Chain Mail — product of the armorsmith during the Middle Ages. Intended for body protection, but due to sloppy heat treating, lost many a good customer — permanently.

Science Assures Uniform, Top Quality at LAKESIDE

First, the scientific approach to your steel treating; next, the scientific follow-through; and finally, the scientific test. Accomplished by expert consultation, the use of a practical variety of mechanized, precision controlled processes and accurate final inspection testing. Thus, Lakeside maintains highest "per piece" standards, for large volume steel treating on short notice.

OUR SERVICES . . .

Electronic Induction Hardening
Flame Hardening
Heat Treating
Bar Stock Treating and Straightening (mill lengths and sizes)
Annealing, Stress Relieving
Normalizing
Pack, Gas or Liquid Carburizing
Nitriding, Speed Nitriding, Aerocasing
Chapmanizing, Cyaniding
Sand Blasting
Tensile and Bend Tests

THE *Lakeside Steel Improvement Co.*

5418 LAKESIDE AVE., CLEVELAND 14, OHIO HENDERSON 9100

Abnormal Creep

(From p. 280) air cooled from 1690° F. to obtain a uniformly fine structure and to eliminate the effect of ferritic grain size. Therefore, "grain size" in the following applies to the McQuaid-Ehn grain size.

Within the limits investigated, manganese, silicon and molybdenum reduced the creep rate, and abnormal creep resulting from aluminum additions was reduced, but not eliminated, by these elements. All the steels which showed high creep rates were fine-grained, but not all the fine-grained steels exhibited high creep rates. Fine-grained steels in the higher ranges of manganese, silicon and molybdenum exhibited no abnormal creep unless an excess of aluminum was present.

Except with the steels containing high residual molybdenum, transition from normal to abnormal creep rates was abrupt. The transition from coarse to fine grain size was more gradual. The creep characteristics of steels with mixed grain size approximated those of the coarse-grained steels. It appears therefore that more aluminum is necessary to produce abnormal creep than is required to make the steel fine-grained. In normal production of openhearth mild steels, the two effects follow each other so closely that practically all fine-grained steels of this type give abnormally high creep rates. On the other hand, the judicious use of manganese, silicon and residual molybdenum permits fine grain without abnormal creep.

A few 1000-hr. tests were made in the range of 500 to 800° F. At 500° F. creep was the same for coarse and fine-grained steels. Above 600° F. fine-grained steels showed progressively more abnormal creep than the coarse-grained as the temperature rose, although the presence of 0.11% molybdenum was sufficient to cause the fine-grained steels to behave more or less normally. At temperatures of 800° F. and higher, this amount of molybdenum was not quite sufficient to counteract completely the effect of aluminum.

It would appear, therefore, that the deterioration in creep properties is appreciable in normal low-carbon steels only when the aluminum addition is sufficient to give the steel a fine McQuaid-Ehn grain size. Likewise, aluminum may be used as a deoxidizer provided the steel remains coarse-grained by the McQuaid-Ehn test.

R-S Furnace Facts

FOR THOSE CONCERNED WITH QUALITY HEATING OF METALS

2 ROOMS AND BATH...

Here is a highly efficient R-S electric batch type furnace for treating aluminum aircraft parts at Republic Aviation, Farmingdale, L. I., New York.

This can be run as a single chamber if desired but becomes a 2-room furnace when you drop the middle lift door. Each chamber has a circulating fan. In normal operation the loaded racks are moved by conveyor chain beneath the floor into the high temperature chamber. After treatment a limit switch opens an intermediate door, starts the conveyor motor and a circulating pump in the quench chamber adjoining the furnace at the nearer end in the pic (door open). The parts are moved quickly into the quench chamber. After quenching they are moved slowly to the outside track and around to the low temperature chamber at the far end of the furnace for aging.

JMLco PH-1

A heat-treating plant in Bellaire
Found maintenance causing despair
When they bought an R-S
You can easily guess
Their troubles dispersed in the air.

It is clear that the longer you plan to keep a thing—such as a furnace, a capital investment—the more important maintenance becomes, and the less important the first cost. A policy of buying always at minimum bid figures must inevitably lead to high maintenance figures. The figures of the A.I.S.E. show that Maintenance in the Steel industry is 3 times Profits.

That's an Equation, Son!

But it ceases to be an equation in any plant where R-S Furnaces do the work. Furnaces that run for YEARS at a minimum expenditure for upkeep are a handsome investment because they add directly to operating profit.

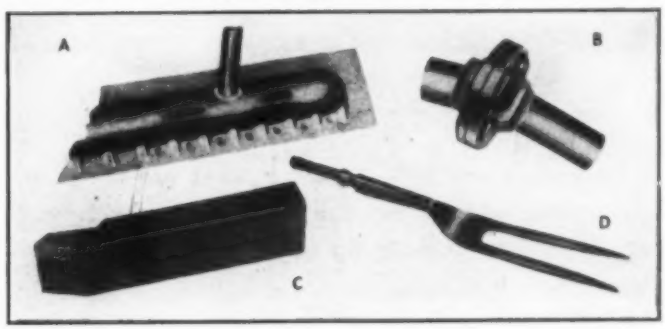
R-S Products Corp.

Give Your Production a Lift with APW

NO. 217 SILVER BRAZING ALLOY

APW No. 217 is tops for low temperature production brazing of steel, stainless steel, alloy steel, copper, brass, bronze, Inconel and monel metal. Only small amounts are needed to make clean, sound, leak-proof joints.

Tested and approved by leading manufacturers... here are a few typical applications:



A-Stainless Steel & Copper Refrigerator Sub-Assembly. B-Brazed Steel Universal joint. C-Carbide Tool Tip brazed to Shank. D-Stainless Steel Fork Assembly.

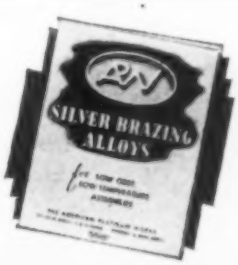
APW NO. 217 ALLOY IS FURNISHED IN WIRE COILS, STRIP, SHEET, WIRE RINGS, WASHERS, DISCS AND SPECIAL INSERTS.
ANY FORM • ANY SIZE ANY QUANTITY.

THERE'S AN APW LOW TEMPERATURE SILVER BRAZING ALLOY FOR EVERY PURPOSE

●

APW No. 369 PASTE FLUX

Gives maximum protection to metal surfaces being joined and actively promotes flow of molten alloy. Easily soluble in hot water.



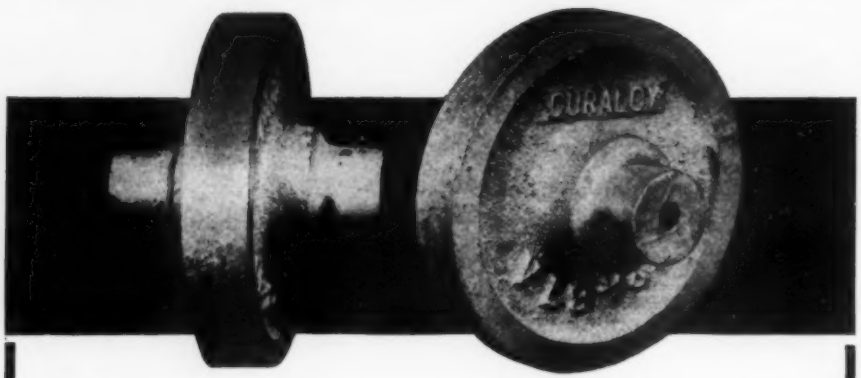
●

Send for our new folder 45W.

THE AMERICAN PLATINUM WORKS
231 NEW JERSEY R.R. AVE., NEWARK 5, N. J.
PRECIOUS METALS SINCE 1875

DURALOY

HIGH ALLOY CAST ROLLER . . . Weight 1 7/10 pounds



25% Chromium and 12% Nickel . . . these are the principal elements selected to provide these small rollers with the heat-resisting strength to carry the heavy loads in an annealing furnace.

But there's more to producing consistently sound castings than knowing which and how much of the several alloying elements to use. High alloy foundry experience is even more important. Shop facilities as well as quality and conditioning of the molding sand used count heavily toward satisfactory castings. These and other important contributing factors can be found in the background of the casting service offered by Duraloy Metallurgists and Foundrymen.

We would like to produce *your* high alloy castings. May we quote on your next requirements?

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Office and Plant: Scottdale, Pa. • Eastern Office: 12 East 41st Street, New York 17, N. Y.

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8-DU-1

CLARK

TOMORROW'S ACCURACY TODAY

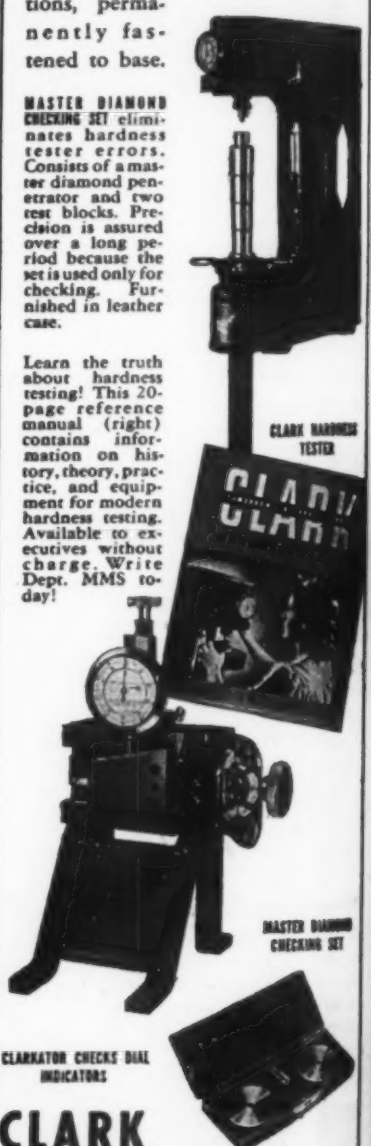
Gives Continued Accuracy, Rapid Measurements

THE CLARK has everything you want in a hardness tester—direct reading precision dial, durable construction, ease of servicing. Three standard models shipped complete with weights, dust protectors, diamond and steel penetrators, test blocks, and anvils.

CLARKATOR CHECKS DIAL INDICATORS with micrometer speed and sine bar accuracy. Easy to operate—just four simple steps. Complete instructions, permanently fastened to base.

MASTER DIAMOND CHECKING SET eliminates hardness tester errors. Consists of a master diamond penetrator and two test blocks. Precision is assured over a long period because the set is used only for checking. Furnished in leather case.

Learn the truth about hardness testing! This 20-page reference manual (right) contains information on history, theory, practice, and equipment for modern hardness testing. Available to executives without charge. Write Dept. MMS today!



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